Human dimension of conservation planning:

the case of Madagascar at national and regional scales

By

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Abstract

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This dissertation is placed at the center of debates over adding human dimension to reserve selection in Madagascar. For many years, we knew that forested lands are cleared at an alarming rate. And for many years, decision makers in conservation planning were aware of the necessity to address human needs have at the same time saving habitat for species if we were to be successful in conservation program. However, No effort has been undertaken in Madagascar to include the human dimension. Instead conservation program continues to conflict with local communities dependant on natural resources for their subsistence. I looked at the National scale to address the issue of selecting reserve network while considering different socio-economic costs. The results show that inclusion of cost in conservation planning did not drastically differ to current design. At regional scale, I looked at the design of Community based natural resources management established around Makira Protected Area. The result suggests that current involvement of community in conservation activities is not likely to stop deforestation.

In chapter II, I modeled rice field expansion in Madagascar, analyzed the different parameters that influence land use suitability for rice, and predicted the location of changes under different future scenarios. The specific objectives are to map existing rice fields and produce a model of suitable land for rice cultivation under current climate and conditions, understand the parameters influencing the expansion or constraints on rice cultivation, and predict the spatial location of future rice cultivation under assumptions of increasing population and future climate change. Analyzing and interpreting the change in land suitability based on circumstances that drive the changes provide essential information to decision makers and enable them to respond adequately to development and conservation issues. I found that land suitability value decreases with increasing slope, the model is improved if I use geology, a proxy for soil variables, to stratify the data, a significant portion of currently cultivated rice fields will experience drier and warmer conditions in the future, and large shifts to the northern and western side were observed under future climate scenarios and as much as 36% of current lands may become unsuitable.

In chapter III, I re-examines the effectiveness of the reserve network proposed by Kremen et al. (2008), by looking at the possible conflict in the existing protected areas given the integration of various costs into the process of network reserve selection. After looking at the possible changes needed in the design of current conservation areas in Madagascar when

introducing cost to conservation planning, I also investigate what changes would be needed to take into account the effect of future suitable agricultural land (under future climate change scenarios) in planning the reserve network, and provide recommendations for the expansion and priority setting of new PA priority sites. My results show that at the national level, inclusion of costs in systematic conservation planning did not drastically change the design of the current reserve network. The effect of including costs may be more pronounced at the regional scale. My results were inconclusive with regards to taking into account shifting costs resulting from future climate change. I conclude by giving recommendations regarding new reserve areas regarding the government priority for setting up additional conservation areas.

In chapterIV, I explore the current status of the Makira Protected Area, and analyze the relationship between land uses to a community management strategy. I first examined how the forest management contracts were set up and administered, and then assessed the efficacy of these contracts with respect to institutional effectiveness (Ostrom, 1990) and reduction of deforestation, the key driver of biodiversity endangerment in Madagascar (Harper, Steininger, Tucker, Juhn, & Hawkins, 2008; Kremen et al., 2008). In this study, I first present a qualitative narrative of the processes of establishing management transfer. Second, I evaluate the forest management contracts in Makira Protected Area relative to the 8 design principles of Ostrom (1990) for management of common property resources. Third, I present data from household surveys showing the prevalence of deforestation in forest management contract areas.

Table of Contents

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Chapter I

General introduction

Conversion of forests into agricultural land and pasture is the main driver of land use and land cover change in tropical regions. Globally, 13 million ha per year of natural forests have been lost over the last decade, chiefly due to agricultural expansion. Madagascar is no exception, with deforestation caused by agricultural expansion continuing to be the main driver of land use/ land cover change as it has been for decades. Madagascar now has little more than 15% forest cover remaining, with subsistence agriculture and relatively small farms visibly dominating the landscape.

While agricultural expansion directly provides food and development for humans it also contributes to global climate change that itself will have a negative effect on agricultural productivity. Agriculture is a source of greenhouse gases, via tillage by reducing soil carbon, Nitrous oxide emission from manure and fertilizer, and biomass burning. Agriculture and forestry combined produce 30.9% of anthropogenic GHG emission (IPCC 2007). Climate change is expected to alter crop productivity and to shift where different crops can be grown, based on their environmental tolerances. Some areas will experience water surpluses while others will experience deficits. A model simulation suggests that by 2080, arid and semi-arid land (less than 120 days length of plant growing-days) on the African continent is expected to increase by about 5 to 8% (Fischer et al. 2005). In addition, a decline of up to 6% in cereal production is expected under all climate change scenarios.

For the case of Madagascar, current climate change model projections predicted an overall consistent increase in temperature between 1.1^{o}C to 2.6^{o} C, for the period 2046-2065 across the country (Tadross et al. 2008; Hannah et al. 2008). Madagascar's very likely to be affected by the future climate change given it's highly dependence on agriculture. With a high population growth of 2.7% per year, agricultural land are expected to expand, particularly for rice production while climate change is expected to constrain land areas for production making it likely to conflict with protected areas and forest reserve networks.

Future climate change adds another layer of complexity and uncertainty to conservation planning because of the need to accommodate species adaptation while at the same time addressing future human needs. At the regional level, the effect of climate change has major implications for species distribution. Many species' habitats are now restricted to small areas of natural forest. Given that many species' habitat has already been lost or fragmented and that species may need to shift to follow their climate niches, protecting corridors between forest fragments is of paramount importance. However, these conservation actions are often in direct conflict with human needs, particularly agriculture production.

Madagascar is known as country of biodiversity hotspot (Mittermeier et al. 1998) as more than 86% of species in the country are not found elsewhere in the world (Harper et al. 2008).

Madagascar has a high level of species endemism but also has many endangered habitats because of human actions such as deforestation. While there is continuous loss of species habitat due to deforestation, the annual rate has decreased relative to a decade ago. In response to the observed human threats, coordinated efforts between international and national organizations have taken place to set up a reserve network for biodiversity protection. A steady increase in the area protected in Protected Areas has been observed since 1991. Currently, Madagascar lists over 150 protected areas totaling over 6.5 million hectare of protected land(Maiorano et al. 2006; Rebioma 2009). However, resembling too many conservation plans developed around the world that put emphasis on biodiversity protection, many of these conservation planning did not include differential land costs and vulnerability and threat to species habitat across land areas. Thus risking conflicts with Madagascar's population, which is highly dependent on natural resources. These various studies agree that agricultural land use practices interfere with current conservation policy and there is a strong need to devise new solutions to remedy the conflict between agriculture and biodiversity conservation.

The aim of this dissertation is to provide a general framework for conservation planning exercise either at regional scale when looking at the efficiency of community based natural resources management or at national scale. My research began with the exploration of general solution on the conflict between human needs and conservation planning. I realized the multiple layers of conservation planning need to be addressed from a regional conservation action, which deals directly with people living around protected areas, to national action where Madagascar is seen as one homogenous block. I started to look for the response of local community to different conservation policy. I looked in Particular at the paths where household become more/less dependent to natural resources. I also looked at the design of component of conservation policy such as community based natural resources management and I analyzed its effectiveness to deal with forest degradation. I looked at the process of selecting reserve and the application of costs in order to avoid location where there are conflicts between human and biodiversity. I realized that cost layer has to be created as. Here I provide a general framework of producing agricultural suitability maps, by illustrating with the example of irrigated rice fields.

Chapter II

Land use modeling in Madagascar: A case study of rice paddy field expansion under climate change

Summary

Madagascar is one of the largest rice producers and consumers outside of the Asian continent. Historical data shows that land for rice fields has increased on the order of 10,000 ha per year in the last 50 years across regions in Madagascar. There is however a lack of understanding of how the rice fields will expand in the future and the variables that will affect expansion, including the influence of climate change.

I modeled the distribution of rice fields in Madagascar using Maxent, software for environmental niche modeling based on maximum entropy. I integrated 22 biogeophysical explanatory variables into the model and used the current distribution of rice fields as the response variable. I then used three climate change models to predict future locations of rice in order to observe the possible expansion or reduction of suitable land. Results of the Maxent model under the current climate scenario illustrated suitable land for rice fields up to four times the size of the currently cultivated area. I analyzed the different variables that influence land suitability for rice fields. Among our different results I found that (1) land suitability value decreases with increasing slope, (2) the model is improved if I use geology, a proxy for soil variables, to stratify the data, (3) a significant portion of currently cultivated rice fields will experience drier and warmer conditions in the future, and (4) large shifts to the northern and western side were observed under future climate scenarios and as much as 36% of current lands may become unsuitable.

Introduction

Conversion of forests into agricultural land and pasture is the main driver of land use and land cover change in tropical regions. Globally, 13 million ha per year of natural forests have been lost over the last decade (FAO 2010a), chiefly due to agricultural expansion (Foley et al. 2005). Madagascar is no exception with deforestation caused by agricultural expansion continuing to be the main driver of land use/ land cover change as it has been for decades (Kull 1998; Marcus & Kull 1999; Gorenflo et al. 2011).

The need of a growing population to feed itself is an important leading cause of the expansion of subsistence agriculture in developing countries. In Madagascar for example, local people have been accused of destroying the unique forest that contains countless endemic species for agricultural purposes (Kull (2000); and Gezon (2007) provide detailed reviews). Other triggering factors include government's push for economic development (e.g. Soares-Filho et al. 2004; McConnell, Sweeney, and Mulley 2004; Veldkamp and Lambin 2001; Jarosz 1993), land tenure conflict at local level or inappropriate policy interventions for conservation and development purposes (Ferraro 2002; Laney 2002; Nambena 2003).

Natural forest conversion to agriculture disrupts global climate not only by releasing large quantities of greenhouse gases (GHG) such as CO_2, CH_4, and N_2O into the atmosphere, but also by altering the source-sink dynamics (of carbon and other materials) that are important for maintaining the terrestrial ecosystem. Agriculture itself is also a source of greenhouse gases, via tillage by reducing soil carbon, Nitrous oxide emission from manure and fertilizer, and biomass burning. Major source of methane emission includes rice farming and cattle production. As of 2004, agriculture cultivation causes 13.5% of greenhouse gases in the atmosphere. When added together with forestry (17.4%, including deforestation for agriculture), this totals 30.9% of total anthropogenic GHG emission (IPCC 2007). Agricultural expansion directly provides food and development for humans but also contributes to global climate change that itself will have a negative effect on agricultural productivity (IPCC 2007).

There is a general consensus that climate change will affect developing nations that rely predominantly on agriculture for their economy (IPCC 2007). The effects of climate change on agriculture have been the subject of many comprehensive analyses at the global scale e.g. (Fischer et al. 2005), for the Asian continent (Matthews et al. 1995), for sub-Saharan Africa (Thornton et al. 2011), and specifically for Madagascar (Randrianarisoa & Minten 2001; Hijmans 2009). Climate change is expected to alter crop productivity and to shift where different crops can be grown, based on their environmental tolerances. Some areas will experience water surpluses while others will experience deficits. Rain-fed agriculture will be particularly vulnerable to climatic shifts. A potential positive effect of climate change is that temperature will generally increase across regions which may extend (or shift) the growing season. The best case scenario is that there will simply be a shift in the season of crops. Another expected climate change impact suggests reduction of crop yields due to the increased frequency of extreme weather events.

A simulation under Agro-Ecological Zone modeling (Fischer et al. 2005) suggests that land suitable for cereal production will be constrained in some locations and may completely disappear in others. By 2080, arid and semi-arid land (less than 120 days length of plant growing-days) on the African continent is expected to increase by about 5 to 8%. In addition, a decline of up to 6% in cereal production is expected under all climate change scenarios. Madagascar is one of the largest rice producing and consuming countries in Africa (FAO database). Madagascar's rice production reached 4 million tons in 2009, making it the eighteenth largest producer and ninth largest consumer, per capita. Rice is grown on over 1.3 million ha of land in all regions of Madagascar except the arid south, and is the main food crop and staple. Rice is mostly cultivated on paddy fields which are found in rain-fed lowland zones, flood prone zones, wetlands, and irrigated upland fields or terraces. Wetlands are the most desired land type to transform into irrigated rice fields because of their all-year access to water. Rain-fed rice is also produced in uplands, usually after the forest has been cleared. This is the alternative land to use when all possible irrigated lands have already been utilized. Agricultural land for rice production has been increasing on the order of 10,000 ha per year in the last 50 years in Madagascar (See Appendix for details). Rice cultivation represents an average of 44% of arable land which has remained constant despite an overall increase in total arable land (50%) since 1961 levels (FAO 2010b). With a high population growth of 2.7% per year, agricultural land expansion, particularly for rice production, is expected to continue.

Different land use modeling techniques presented in the literature all use the capability of quantitative statistical modeling coupled with Geographical Information Systems (GIS). Spatially explicit land use modeling offers the possibility to identify key variables and then modify them to predict possible outcomes for spatial pattern and land use trajectories. By changing the key variables to simulate future conditions, such models are useful for scenario-based decision making (e.g. Nelson et al.:2009), although interpreting results of spatially explicit models should be done with caution. It is, however, difficult to assess impacts of agricultural expansion alone due to the fact that progressive land use and land cover changes, such as the transformation of land to agriculture, are occurring at a small scale simultaneously with large episodic changes such as anthropogenically-induced climate change at the global scale (see Veldkamp and Lambin 2001; Lambin, Geist, and Lepers 2003 for full review).

This study models rice field expansion in Madagascar, analyzes the different parameters that influence land use suitability for rice, and predicts the location of changes under different future scenarios. The specific objectives are to (1) map existing rice fields and produce a model of suitable land for rice cultivation under current climate and conditions, (2) understand the parameters influencing the expansion or constraints on rice cultivation, and (3) predict the spatial location of future rice cultivation under assumptions of increasing population and future climate change. Analyzing and interpreting the change in land suitability based on circumstances that drive the changes provide essential information to decision makers and enable them to respond adequately to development and conservation issues.

Materials and methods

I built a conceptual framework to help order and orient the model (Fig. 1). The framework helps distinguish response (rice field) and explanatory variables (bio-geophysical factors) and isolate the desired model outcomes. The current climate explanatory variable was then replaced by the general circulation climate model in order to project the response variables into future conditions..

Suitability of land for agriculture depends on both bioclimatic and soil characteristics. Different bioclimatic characteristics define the amount of heat, light and available water, while soil-type provide mineral nutrients resources for crops (Mackey & Lindenmayer 2001). Socio-economic variables such as population density, land value, infrastructure (roads and irrigation systems) also influence the selection of agricultural fields (Matthews et al. 1995; Lambin et al. 2001; Gorenflo et al. 2011). I carefully looked at the relevance of each of these variables in predicting the suitability of land for rice agriculture (Table 1). In this research, however, I did not include socio-economic parameters for the reason that while they may help explain the current distribution of farmed land, I assume that they do not contribute to the physical characteristics that make land more or less suitable for rice cultivation. Thus I do not expect these variables to influence the shifting of cultivated rice areas under climate change, unless they themselves respond to climate change, but modeling the response of these variables to climate change was beyond the scope or this study.

Other variables include terrain elevation, slope, and distance from both seasonal and permanent rivers where water can be diverted for irrigation. Irrigated rice fields are usually located in flooded zones or close to rivers because of the need for water. Thus, I expected a larger area of rice fields around lakes, rivers, and on the alluvial deposits near water sources. Elevation and slope are commonly used in many land use modeling exercises (Veldkamp & Lambin 2001; Lambin et al. 2003).

Area Information and Data Layers

Madagascar is the fourth largest island in the world with 587,000 km^2 of land area and an estimated population of 22 million. The country's economy is based largely on agriculture, forestry and fishing which constitute 28% of the national GDP (African Economic Outlook 2012). The latest land use mapping effort (Moat & Smith 2007; FAO 2010b) described 41 million ha of land categorized as agricultural land which include perennial crops such as coffee, fruit and spice trees, and pasture lands. Arable lands were estimated to be less than 3 million ha. Forest cover was estimated to be less than 13 million ha including all parks and reserves. A map drawn by Cornet (1972) subdivided Madagascar into 5 bioclimatic zones: humid, sub-humid, dry, sub-arid, and mountainous zones. This subdivision is important for agricultural land use and particularly rice production.

I acquired land use data from different sources such as Madagascar's geographic institute and land survey (FTM), the state forestry department (MEFT), and researchers from different NGOs (e.g., VEGMAP project; Moat & Smith:2007). Each map alone was incomplete so I aggregated data across maps. Land use maps were based on classification of satellite images or aerial photographs, and field visits. Also raw land use maps were produced from data obtained between 1974 and 2001 with scales ranging from 1:50,000 to 1:500,000. All maps were previously classified but many required spatial correction. I also corrected for temporal errors by cross- referencing maps from the same time period. Identification of irrigated rice fields may be biased toward the large visible areas of human land use, systematically ignoring fields of smaller size or fields smaller than the image pixel size. Rice field classifications were based on Landsat 7 images. The highest resolution of these images is 28m x 28m and therefore fields of less than $900m^2$ could not be detected. Coarse temporal resolution may add errors in mapping irrigated rice fields for two reasons. First, some irrigated rice fields may be planted for two successive seasons in one year while others in the same location may not. As a result, two sets of satellite images or aerial photos have to be available for any given location to ensure that all fields will be identified. This is rarely the case in practice when compiling data. Second, weather conditions during the image acquisition play an important role in the identification of rice fields. During the wet season, flooded zones can be misinterpreted as irrigated rice fields, while during the dry season, dry rice fields are simply not detected.

Climate data at 30 arc-second downscaled resolution using delta method (Hijmans et al. 2005) were downloaded directly from the WORLDCLIM database. I generated 19 bioclimatic variables typically used in environmental niche modeling from monthly temperature and rainfall data following the method of Ramírez and Bueno-Cabrera (2009). A list and explanation of the meaning of each variable are in the appendix. Of the many climate data available in the WORLDCLIM database, I selected the high resolution global climate layer for year 2000 and the climate layer projection for year 2050. For future projections, I selected the three most commonly used General Circulation Models (GCM) datasets, the Hadley Centre Coupled Model, version 3 (see Gordon et al.:2000), the Atmospheric Research climate model (see Hirst, Gordon, and O'Farrell 1996 for details), and the Canadian Centre for Climate Modeling and Analysis, Third Generation Atmospheric General Circulation Model (see Scinocca et al. 2008 for details). For each GCM, the Special Report on Emissions Scenarios (SRES) A2a was chosen. This scenario is influenced by high population growth and land use change, with slow technology changes and high energy requirement, and thus represents a worst-case scenario.

Since no soil map of Madagascar exists, I used a geological map of Madagascar (Du Puy & Moat 2003) as the best available proxy for soil type. The geological map identifies 8 classes of bedrock. The majority of soils in Madagascar rest on top of igneous and metamorphic rocks, and these have the highest proportion of rice fields compared to other basement rocks.

Modeling and cross-validation

I used Maxent (version 3.3.3e), an environmental niche modeling software (Phillips et al. 2006), to identify the best suitable areas for irrigated rice cultivation. Maxent utilizes a machine-learning algorithm, with presence-only records and random background data to compute the probability of occurrence of an event in a defined geographic range. Prior to selecting maximum entropy modeling, I considered other modeling tools such as General Additive Model (GAM), General Linear Model (GLM), that can be used for spatially explicit modeling applied to ecology (Zuur et al. 2009), and also other presence-only modeling approaches such as DOMAIN (Carpenter et al. 1993). I selected Maxent based on a comprehensive survey that found Maxent's predictive performance to be superior or equivalent to alternative algorithms (Elith et al. 2006). To evaluate the response to climate change, I altered the spatio-temporal variables that feed into Maxent to make a spatially-explicit projection of the model to future climate conditions. I focused on future suitable range for irrigated rice fields by projecting the current suitable model into different spatial or temporal variables. The assumption is that the modeled relationship between current rice distributions and current climate and geo-biophysical continues to apply in the future under new conditions of each of these variables. I performed multiple runs of the model to observe changes of area under the curve value (AUC) by randomly adding or removing some samples of the response variable (Phillips et al. 2006). Unlike using the automatic option in Maxent, I provided separate training and test data. I also looked at the relative importance of variables by identifying their contribution to AUC value and their permutation importance. Permutation importance is calculated by changing the variable predictor between presence and background and observing the resultant change in model AUC (Shipley 2010). Permutation importance is appropriate for cross-validation because it depends on the final model not the path to obtain that model. I subsequently removed variables that did not significantly improve model performance and suitability map results. Altering the model complexity by changing the number of variables can affect the model's performance. However, it is generally believed that in maximum entropy modeling it is better to include a large number of variables to account for environmental differences than not to use enough (Warren & Seifert 2011). The practical advantage of working with fewer parameters, however, is to reduce file sizes and thus to speed up computations. Although there is currently no standard way of removing variables to improve computation speed, I removed all variables that were contributing less than 1% to AUC value.

I compiled geophysical and climatic data as explanatory variables and rice/non-rice paddy maps as response variables (Table 1). I randomly selected 10,000 points inside and outside the current rice area; I used the former points as the sampled presence of rice fields to feed into the Maxent software, and considered the points outside the currently cultivated regions as absence points. I enforced a minimum distance between points of 92 m, in order to avoid having multiple points in the same pixel. By randomly selecting points for the response variable, I addressed the issue of sample bias where some regions might be heavily weighted for collecting presence data compared to others. This method was recommended by multiple authors (Phillips et al. 2006; Elith et al. 2006; Phillips & Dudı 2008). Hence, I assumed that the sampling effort is the same across the geographic study area. I integrated the 22 predictor variables into the Maxent model software, after bringing all variables to the same spatial resolution of the Shuttle Radar Topography Mission (SRTM) digital elevation model (92m). I chose this resolution due to the importance of slope in determining suitability of agricultural land. Slope rendered at lower resolution dismisses a good proportion of the landscape in highly variable topographic regions, which constitute a large component of Madagascar's surface. All other variables were up-scaled to this resolution using the GIS resample technique.

To find the average contribution of each explanatory variable, I ran one model for the entire region of Madagascar with 100 replicates, generating what I call the single model. Then, I stratified the input data relative to 8 areas of distinct geology (8 types of bedrock), ran a separate model for each, and then recombined the map outputs in GIS to generate what I call the aggregated map. I compared the performance of the output of the single model with the aggregated map. This comparison was made in order to explore further the effect of geology, the only categorical variable in the model. I specifically looked at two scenarios to better understand changes in land suitability: Scenario (a), suitable land use under current climate conditions; scenario (b), suitable land for rice in the future under the A2a scenario as predicted by three General Circulation Models (GCMs). I looked at the spatial overlap and differences of suitable land for rice fields between scenarios. To explain the change, I compared the current bioclimatic characteristic of rice field distribution (bioclimatic envelope) with the distributions under the three GCMs in 2050.

Instead of relying on AUC values from Maxent, I used R statistics (R Core Team 2012) to evaluate the model performance and to identify the best threshold probability value for projected suitable land. To analyze the output from Maxent software, first, I selected points inside the current map of rice fields (presence) and another set of points outside of the rice fields (absences). Then, I extracted the probability values from the model associated with each point in order to calculate the area under the curve (AUC) of the received operating characteristic (ROC) curve. And finally, I calculated the true positive rate (sensitivity) and false positive rate (1-specificity) using a modified ROCR R statistic package (Sing et al. 2005). Different methods of selecting thresholds values to produce a binary suitability map are discussed in Liu et al. (2005). One method is to minimize the sum of sensitivity and specificity for a random data point. For this study, I selected a cut-off value that looks at equal sensitivity and specificity. This procedure simply means that the presence and absence of rice fields have an equal chance of being correctly predicted by the model (see Freeman and Moisen (2008) for details on this method). A simple GIS layer overlay allowed comparison of the mapped distribution of current rice fields with the modeled threshold result. Calculation of model sensitivity and specificity were based on Fawcett (2006). Formulas are as follow:

Sensitivity: $\frac{\boldsymbol{a}}{(\boldsymbol{a}+\boldsymbol{c})}$, proportion of presence of observed rice fields correctly predicted

Specificity: $\frac{\boldsymbol{d}}{(\boldsymbol{b}+\boldsymbol{d})}$, proportion of absences of rice fields correctly predicted

Where a is true positives (or presences), b is false positives (or absences), c is false negatives (or presences), d is true negatives (or absences).

Results

Based on the map that I compiled from multiple original sources (Fig. 3), the total current irrigated rice field area is about 1.7 million hectares which is 25% larger than previously reported by FAO (FAOstat, 2012). The single model had moderate to good performance when run with all variables with an average AUC value of 0.678. However, the eight models corresponding to 8 bedrock types had higher AUC values ranging from 0.741 to 0.932 (Fig. 2a), a significant improvement of the goodness of fit over the single model (mean difference = 0.1895, p values < 0.0001). I produced the aggregated map of suitable rice fields for the whole country by combining the outputs from these 8 models (Fig. 4). This map has a suitability value ranging from 0 to 0.96. I then produced a binary map from this aggregated map by applying the threshold cut-off values for each of the corresponding 8 models. Any pixel having a value higher than the threshold value was considered an area suitable for rice fields (Fig. 6).

All precipitation related variables combined contributed up to 35.3% to the overall AUC while all temperatures variables contributed up to 20.7% (Table 2). While some variables contributed relatively little to the overall AUC, their removal would have caused disproportionately large changes in the AUC because their permutation values were high (e.g., the percent contribution of elevation was 4.3%, but its permutation value was 23.9%). Slope had the second highest contribution to the single model with 14.9%. A closer look at the probability curve of presence values vs. percent slope curve shows a declining suitability value as slope increases (Fig. 2b), with little suitable lands for rice fields at slopes higher than 55%. When looking at the single model, geology type, a class variable proxy for soil, had the largest contribution to AUC value with 17.8%. It was for this reason that I stratified the model into 8 regions of distinct geology. Across these 8 sub-models, I found no consistent variable that had high contribution to the respective AUC values (Fig. 5).

Using the binary map (Fig. 6), I identified 6.75 million hectares of suitable land for rice fields under the current climate conditions, which is four times the size of currently cultivated rice fields (Fig. 3). Further, future climate change scenarios predicted a gain of suitable land for rice fields over the current climate condition (Table 3a), with a 6% increase for Hadley Centre Coupled Model, (HadCM3), 80% for Atmospheric Research climate model (CSIRO-MK2) models and up to 90% for Canadian Centre for Climate Modeling and Analysis, Third Generation Atmospheric General Circulation Model (CCCMA). When overlaying the maps generated from the three different climate change projections, 3.2 million hectares of suitable lands for rice fields were found to be common to all (Table 3b). Land that is currently cultivated, however, might not remain viable for production in the future. For example, about 1 million hectares (74% of the current area under rice production) would be considered suitable land for production in the future.

I examined the bioclimatic envelope of the current rice field distribution, and all variables show major change in 2050 (across GCMs) compared to current climate. There is clear indication that the current rice cultivation will experience higher annual temperature and lower precipitation under a future climate scenario (Table 4). The analysis predicts major shifts in the suitable area for rice fields across Madagascar. The majority of future rice cultivation areas would be located in the top northern, the northwestern and the western regions of the country (Fig. 7). These shifts can be partially explained by the shifts in precipitation patterns expected in the future across Madagascar (Fig. 8). Fig. 8 illustrates the spatial pattern change in all GCMs compared to the current annual precipitation data. There is a clear decrease in precipitation in the eastern region with a net increase in the western and northwestern regions..

Discussion and conclusion

This is the first study to compile decades of land use datasets and rice field maps at a national scale for Madagascar. The size discrepancy between mapped rice fields in this study and others (e.g. Hijmans:2009) leads to question the validity of previously published data on total rice field area, rice production, and yield at the country level. Spatial errors may cause both underestimation and overestimation of the extent of rice field area. Lack of observation of rice fields in different seasons, as discussed in methods, may also contribute to the area discrepancy between values generated by this research and previously reported values. Another source of error is how abandoned or transformed rice fields are assessed and mapped. While these sources of error also affect the mapping of rice presence points in this study, I have reduced these errors compared to previous work by spatial cross-referencing among maps, and by compiling data sources across time.

These sources of error then influence subsequent models of rice cultivation of Madagascar. Based on his model, Hijmans (2009) argued that there is twice as much land suitable for rice cultivation than is currently used. However, my results suggests that under the current climate scenario there is four times as much suitable land for rice production as is currently cultivated in Madagascar. It is not surprising that my model predicts a larger area of rice suitability than Hijman's (2009) model. First, his model utilized a smaller region of current rice area to generate presence points, based on his more limited mapping of current rice cultivation, which may have overly constrained his model. Second, his study on rice production and expansion in Madagscar included both climate and socio-economic variables; thus, he modeled where people are currently producing rice. I did not include any socio-economic parameters into this study because my aim was to identify the biophysical suitability of land for rice agriculture and to project changes in suitability with climate change.

At the current pace of land conversion, there will be a need for an additional 450,000 hectares of land, or more, for rice production by 2050. According to my model, the unexploited potential area for rice fields is large enough to meet this demand. My model also suggests where this expansion could occur. However, given the availability of high resolution aerial images and cheaper technology, I call for an update of the land use and land cover map for the whole country to reduce model uncertainty using better baseline data. While data is key, another difference between the models revolves around how well a given model can reflect reality. A benefit of using Maxent, which has not yet been used to model rice production in Madagascar, is that once good data is obtained, Maxent has one of the best capacities for performance prediction compared to other models (Elith et al. 2011).

In this study, I used 22 explanatory variables to model the current and future potential areas for rice cultivation. Our analysis illustrated the most important determining variables for rice field suitability as the geology type, precipitation and slope. I observed that land suitability value decreased with an increasing slope while increase in rainfall for the coldest quarter made an area more suitable. Based on future climate conditions in which precipitation shifts to the west and north of Madagascar, my model predicts that these regions will become more suitable for rice cultivation under a warming climate. I improved the goodness of fit of the model by dividing the region into similar geology types and running sub-models, instead of using geology as an explanatory variable. However, within the sub-models, I found no variable to be important across all models.

Caution is required in using maps produced by this model and by land use models in general. First, there is a tendency to translate such maps into probability of conversion of current area into agricultural fields. The real opportunity to expand rice fields beyond the current area depends not only on the parameters I looked at but also on the value of the land and the cost of the investment (e.g. as related to access or other factors). Suitability values must be weighted by other parameters like those in order to convert them into reasonable predictions of expansion. Additionally, my analysis concerns land suitability for rice fields only, which may not be the most important or attractive crop in certain regions of Madagascar.

With regards to current rice cultivation, it is important that the rural population highly exposed to changing condition in the next decades becomes aware of future climate change and prepared to adapt in crop choice or farming techniques. My results suggest a clear indication that a large part of currently cultivated fields will experience drier and warmer condition in the future. Although, many unknowns exist, e.g. frequency of extreme weather, the application of land use modeling should provide a guide to policy in order to prepare and adapt for future changes, given that further population growth is inevitable and that all future GCMs indicate a warmer and drier future including in Madagascar.

The objectives of this study were to map the location of suitable land for irrigated rice fields, identify the zone of possible expansion of current rice fields, and to look specifically at the possibility of expansion or retraction under climate change. However, in a realistic world, the question remains whether people will abandon their land or change their investment in response to future climate change. For example, what crop type would be more appropriate in places where rice can no longer be grown? A simple and comprehensive analysis of options for adapting to the changing climate is difficult partially due to the unknown adaptive ability of both humans and crops to warmer, drier, or harsher climate conditions. Government can play a crucial role in climate change mitigation and adaptation, however, through research, information, or intervention, as in, for instance, in identifying new varieties of crops or strains that are less sensitive to drought and heat.

Table 1: Detail description of variables and data and sources

Data	Relevance	Description of the variable	Accuracy/resolution	Source
Rice field	Rice fields maps, response variable for the model	Center of the pixel that contains rice fields are transformed into points, then randomly selected.	Data range from 250m x 250m resolution to 30mx30m.	FTM (1974 – 2001). Ministry of water and Forestry
Digital Elevation Model and slope	Topo-scaled slope, surface radiation, stratification by location (plateau, mountainous or in coastal area)	Slope ranges from 0 to 70 percent. Raw elevation in meter above sea level from 0 to 2800 meter	Generated from SRTM 92m x 92m	USGS (2004)
River and water bodies	Availability of water key to suitable land for rice fields	Distance from river and any permanent water bodies Iighted with the slope to take into account topography.	Extracted from data base of approximately 92 m x 92 m resolution	FTM (1974 to 2001)
Vegetation map	Latest Land use/cover map prepared with satellite images. This data was used for correction of some spatial errors on the compiled rice field maps.	Vegetation map and other features were used for correction of some spatial errors	28m x 28m resolution	Kew & MGB (2003), Landsat images
Bioclimatic current and future (GCMs)	Bioclimatic variables define the light, heat, and available water for living organisms.	19 Bioclimatic variables generated based on the method of (Ramírez & Bueno-cabrera 2009).	Downscaled climate data to 30 arc second (900 m x 900m resolution)	WorldClim (2011) http://ccafs-climate.org/
Geology map	Proxy for soil type, soil type influences rice cultivation	Divided in 8 classes	Approximately 1km	Digitized by Moat and Du Puy, Royal Botanic Gardens, Kew. From Bessaire (1964)

Table 2: Relative contribution of variables to the model overall AUC. This is an average of 100 models (multiple runs). The first value indicates the percent contribution of the variable to the AUC and the second, the permutation importance which shows the drop in model AUC by removing the same variable.

Variable	**Percent contribution**	**Permutation importance**
Geology (class variables)	17.8	6.2
Slope	14.9	14
Precipitation of Coldest Quarter	11.1	3.1
Temperature Annual Range	10.9	4
Annual Precipitation	8.1	6.1
Distance to river	6.9	6.1
Precipitation Seasonality	6.4	8.1
Elevation	4.3	23.9
Precipitation of Warmest Quarter	3.3	1.8
Mean Temperature of Driest Quarter	3.1	0.3
Precipitation of Wettest Month	2.8	8.3
Precipitation of Driest Month	2	2.1
Max Temperature of Warmest Month	1.8	2.7
Precipitation of Driest Quarter	1.6	0.9
Mean Temperature of Warmest Quarter	1.5	0.2
Temperature Seasonality	1.2	6.6
Isothermality	1.1	4.1
Min Temperature of Coldest Month	0.4	0.4
Mean Diurnal Range	0.3	0.3
Mean Temperature of Coldest Quarter	0.2	0.3
Min Temperature of Coldest Month	0.1	0.5
Annual Mean Temperature	0.1	0.1
Mean Temperature of Wettest Quarter	0	0

Table 3a: Comparison of overlap between current areas for rice cultivation with future area (values are in km2)

		Current area that overlaps with future area	**Current area that does not overlap with future area**
Land currently under rice production (based on mapped rice fields)	*HadCM3*	8,714 *(51%)*	8,269 *(49%)*
	CSIRO	5,503 *(32%)*	11,480 *(68%)*
	CCCMA	7,700 *(45%)*	9,284 *(55%)*
Land suitable for rice production(based on model rice fields)	*HadCM3*	39,981 *(59%)*	27,555 *(41%)*
	CSIRO	25,344 *(38%)*	42,192 *(62%)*
	CCCMA	33,497 *(50%)*	34,039 *(50%)*

Table 3b: Total areas under all models of land suitable for rice production (values are in km2)

Baseline: Identified as suitable now by model with current climate data	67,536
Total predicted suitable in the future under each scenario:	
• *HadCM3*	59,833
• *CCCMA*	128,460
• *CSIRO*	121,873
Region of overlap between all three GCMs and the model under current climate conditions	15,605

Table 4: Climate envelope of rice fields and predicted range under CCCMA model

CCCMA scenario is chosen here to compare with the current condition because of its greater shifts compared to CSIRO and HadCM3. Temperature values are in degree centigrade *10, and precipitation in mm.

	Profile value	*Under current climate*			*under CCCMA scenario*		
	Bioclimatic index	min	Average	max	min	average	max
1	Annual Mean Temperature	141	222.05	275	160	244.68	299
2	Mean Diurnal Range (Mean of monthly *(max temp - min temp))	68	118.11	172	69	120.30	177
3	Isothermality [(Index 2 / Index 7) * 100]	54	66.44	74	55	66.48	74
4	Temperature Seasonality (standard deviation *100)	864	2086.76	3121	813	2026.63	3013
5	Max Temperature of Warmest Month	222	303.39	369	246	328.99	410
6	Min Temperature of Coldest Month	44	126.62	207	67	148.90	226
7	Temperature Annual Range [Index 5 - Index 6]	114	176.77	257	114	180.09	268
8	Mean Temperature of Wettest Quarter	165	242.05	287	181	263.54	308
9	Mean Temperature of Driest Quarter	114	194.79	256	135	223.94	294
10	Mean Temperature of Warmest Quarter	165	243.17	291	182	265.30	318
11	Mean Temperature of Coldest Quarter	106	191.73	256	127	215.55	282
12	Annual Precipitation	337	1439.84	3328	390	1418.53	3318
13	Precipitation of Wettest Month	76	330.07	514	96	329.45	523
14	Precipitation of Driest Month	0	16.81	101	0	9.03	105
15	Precipitation Seasonality (Coefficient of Variation)	37	96.66	143	42	99.12	142
16	Precipitation of Wettest Quarter	206	863.36	1299	227	861.59	1364
17	Precipitation of Driest Quarter	1	62.32	407	2	50.37	407
18	Precipitation of Warmest Quarter	206	730.39	1270	146	672.90	1250
19	Precipitation of Coldest Quarter	1	72.29	673	6	64.11	581

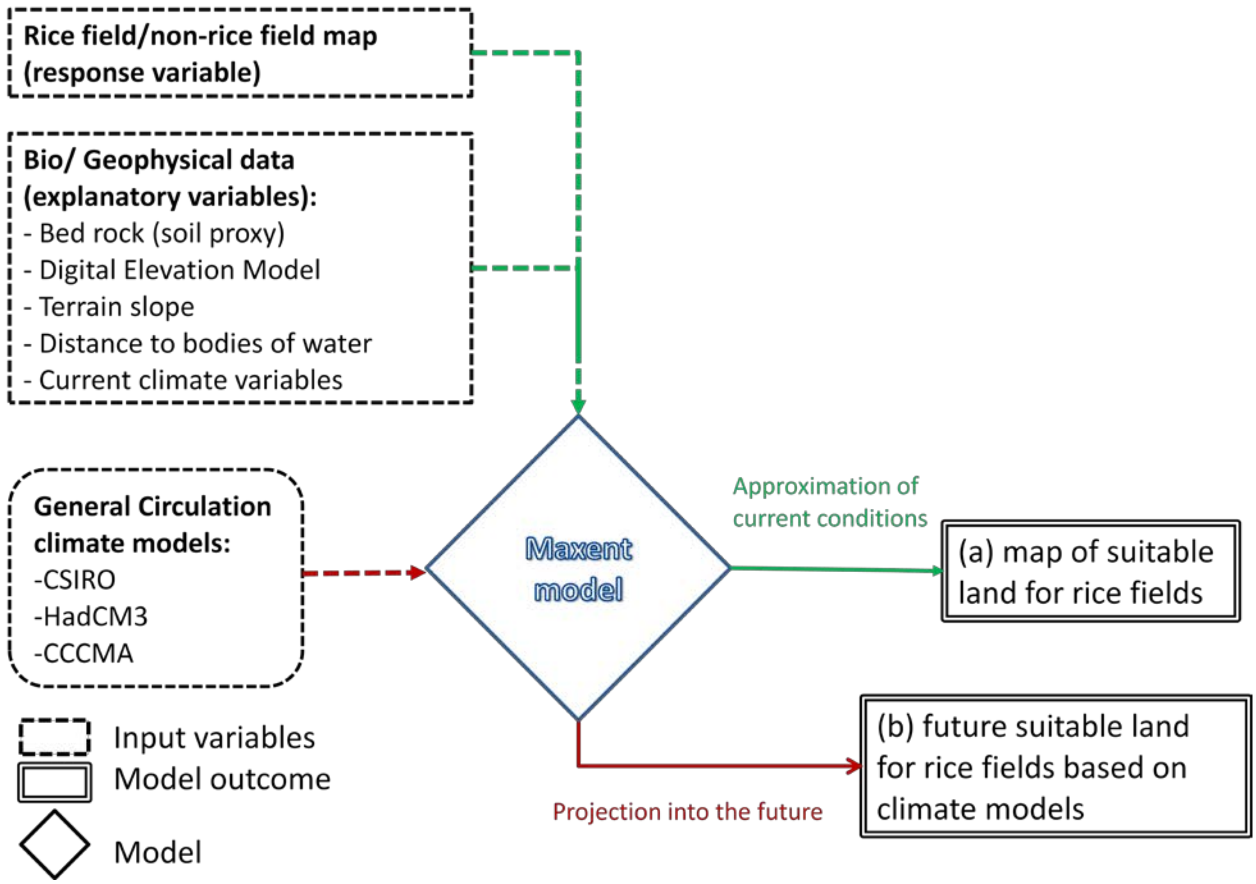

Fig. 1: Modeling framework

Maxent software uses presence points from mapped rice fields to generate the model and then projects into suitable landscapes based on future projection variables.

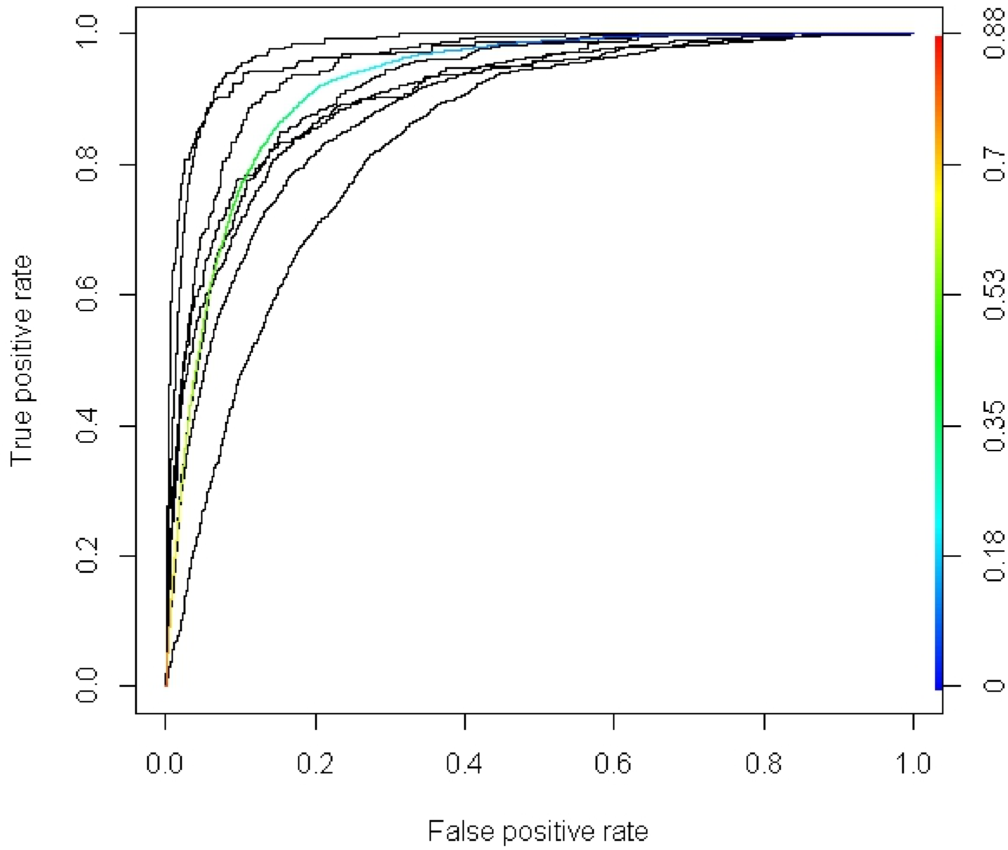

Fig. 2a: ROC curves from all of the 8 models

Curve for each of the 8 models are in black while the aggregated model is colored. AUC ranges from 0.741 to 0.932 with an average of 0.8675. Left axis (in color) indicated the probability value for the aggregated model.

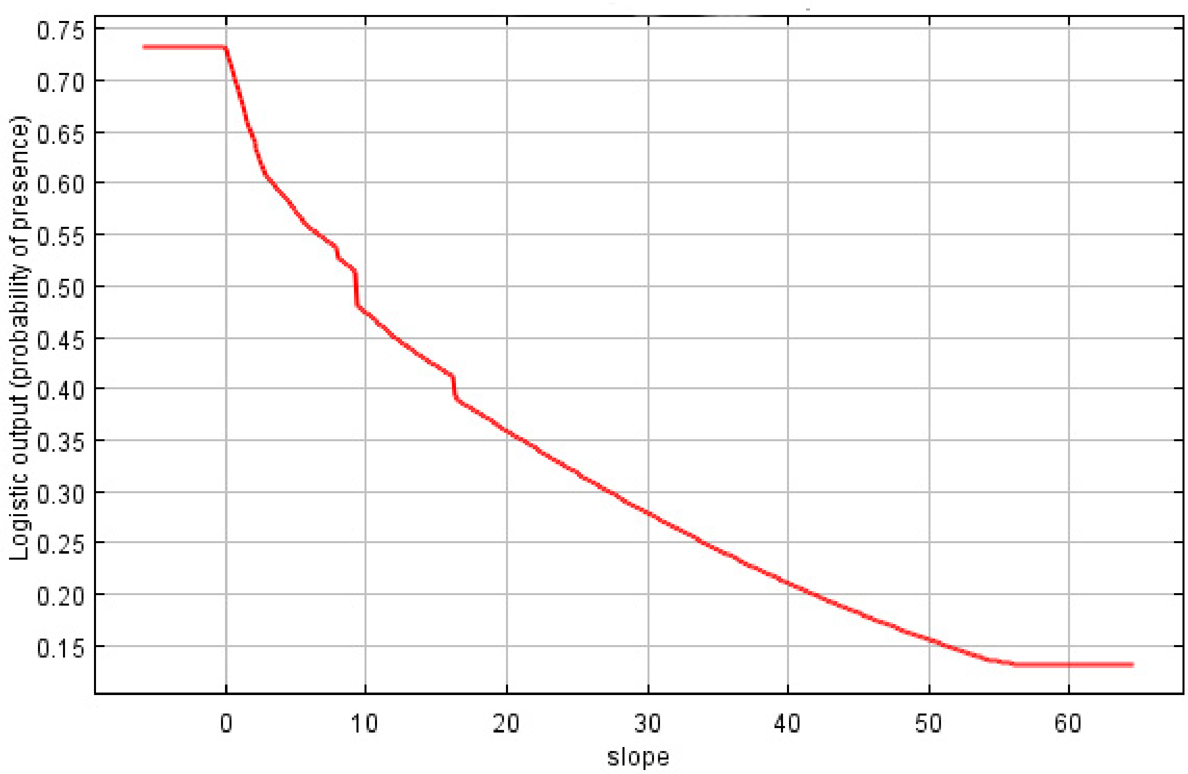

Fig. 2b: change in topographic slope curve with probability value from the overall model.

Slope contributes to 14% of the overall AUC. Suitability values for rice agriculture decline as percent of slope increases.

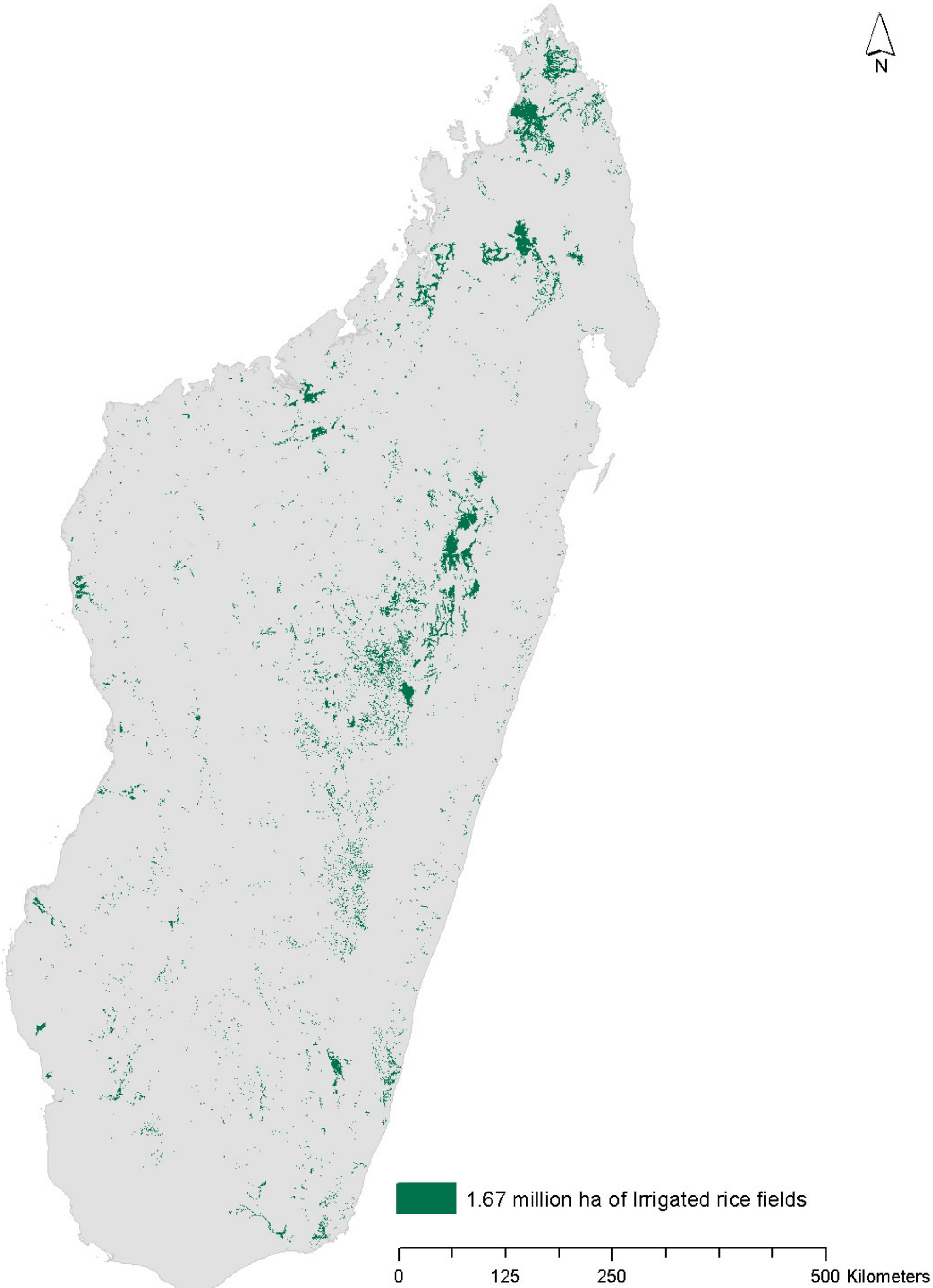

Fig. 3: Map of current rice fields in Madagascar as compiled from different sources, showing a 25% larger rice area than previously reported by FAO (2010b)

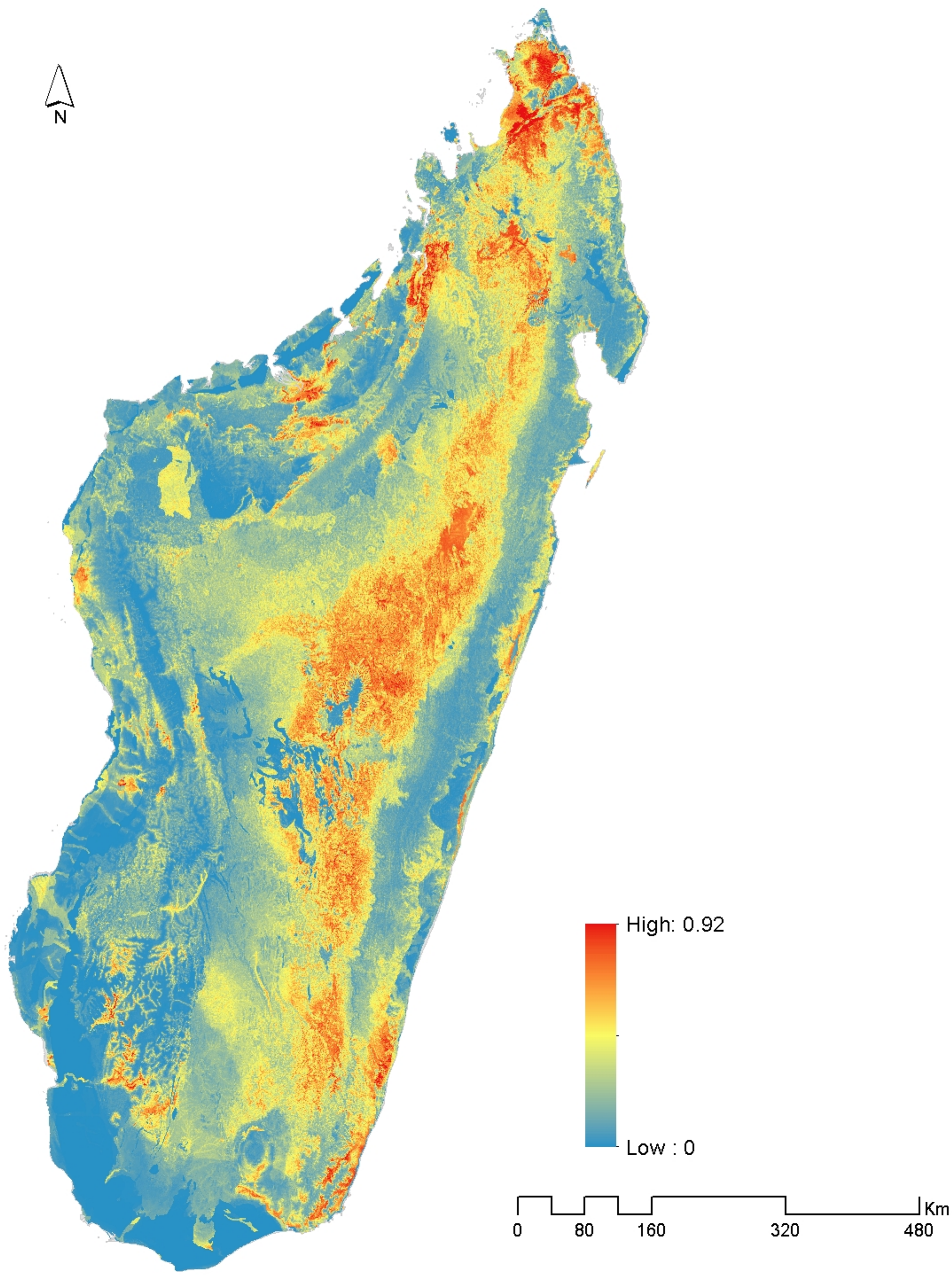

Fig. 4: Maxent distribution of rice fields based on current climate condition, effects of distance to rivers, slope. This is an aggregated map from the outputs of 8 models

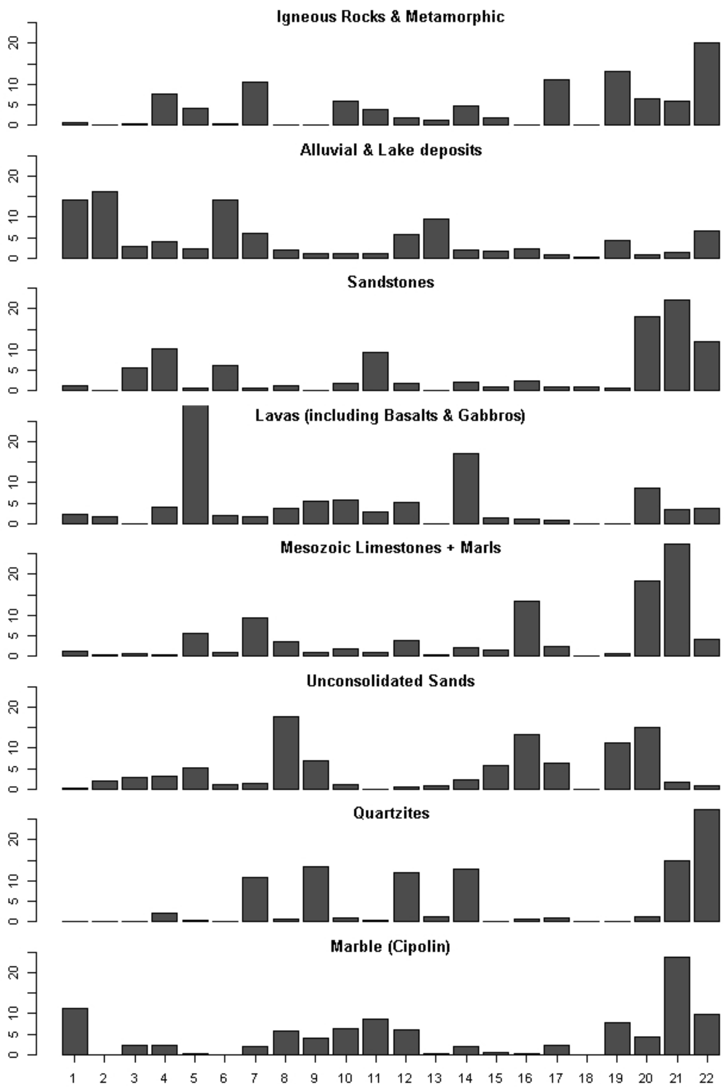

Fig. 5: indicates the estimate of relative contribution of the environmental variables to the model AUC for the 8 models prepared for each distinct geological zone. Variable list: (1) Annual Mean Temperature, (2) Mean Temperature of Warmest Quarter, (3) Mean Temperature of Coldest Quarter, (4) Annual Precipitation, (5) Precipitation of Wettest Month, (6) Precipitation of Driest Month, (7) Precipitation Seasonality (Coefficient of Variation), (8) Precipitation of Wettest Quarter, (9) Precipitation of Driest Quarter, (10) Precipitation of Warmest Quarter, (11) Precipitation of Coldest Quarter, (12) Mean Diurnal Range, (13) Isothermality, (14) Temperature Seasonality, (15) Max Temperature of Warmest Month, (16) Min Temperature of Coldest Month, (17) Temperature Annual Range, (18) Mean Temperature of Wettest Quarter, (19) Mean Temperature of Driest Quarter, (20) Distance from river, (21) Elevation, (22) slope. Refer to appendix for details explanation on each bioclimatic variable.

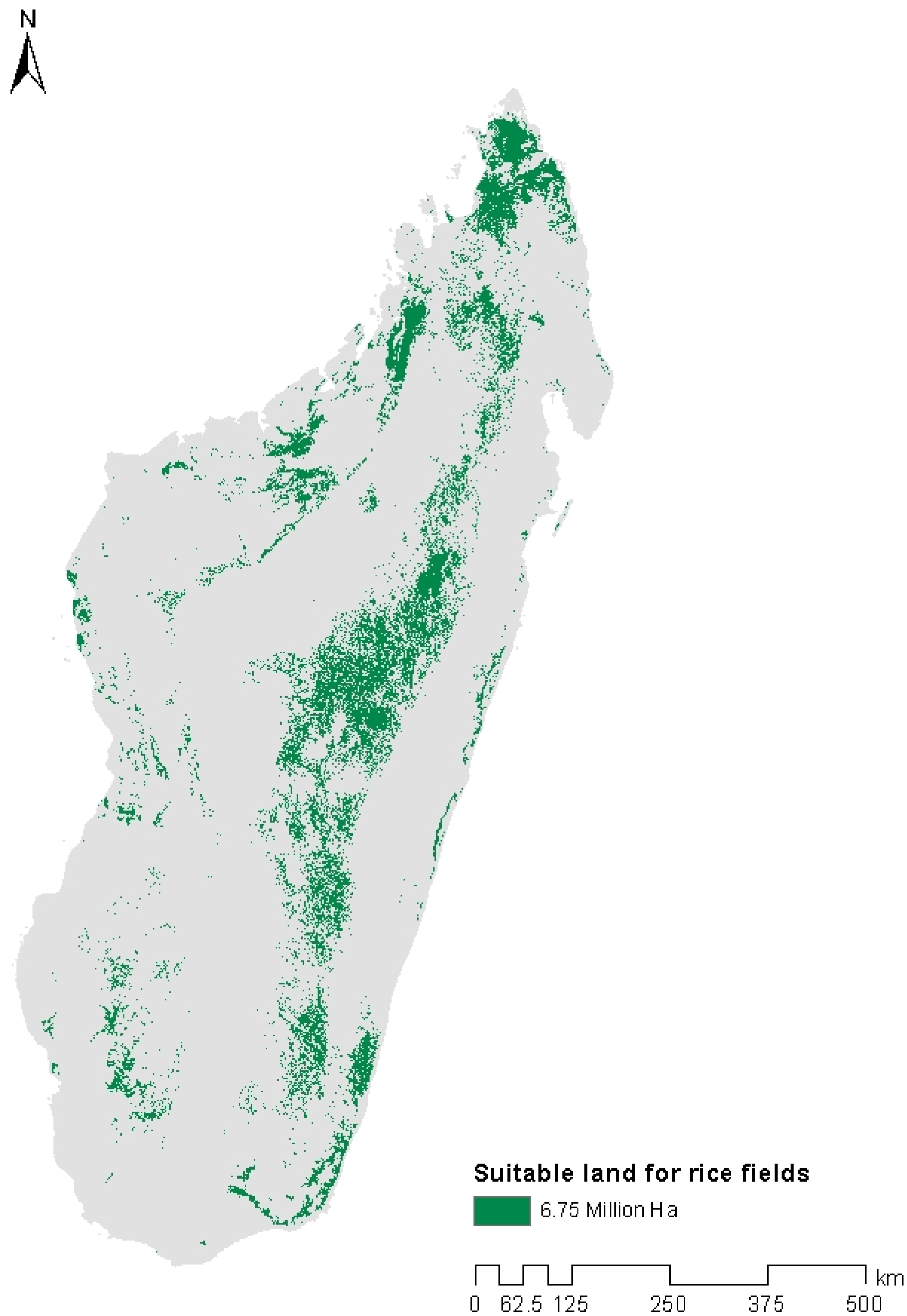

Fig. 6: Binary map of current suitable/non suitable land for rice fields based on the aggregated map. Individual threshold value were applied to each of 8 geology based model, then merged into single map.

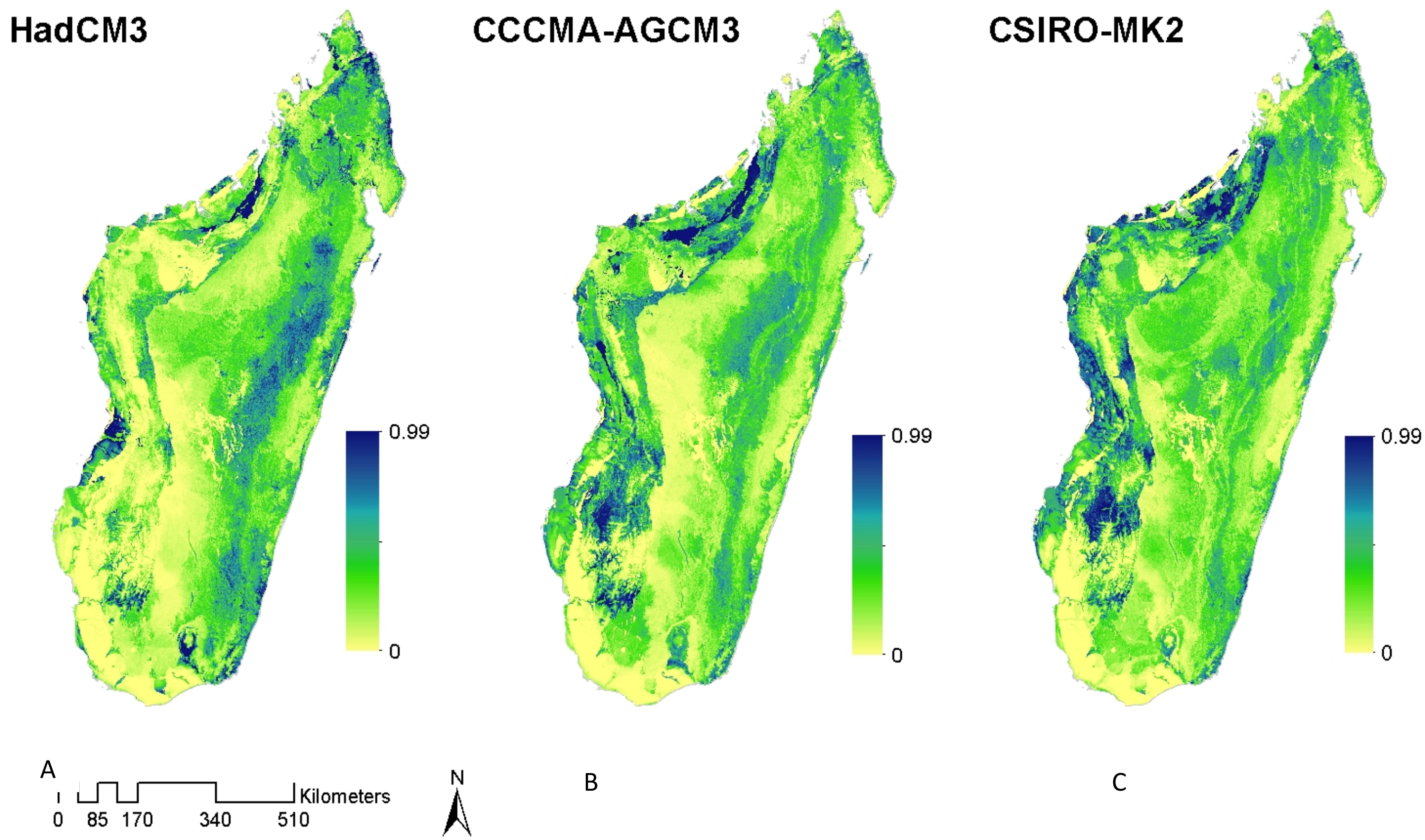

Fig. 7: Model projection of rice field suitability under three GCMs scenarios for year 2050. Model B and C are characterized by the heavy shift of suitability value to the west and north-west side of the country.

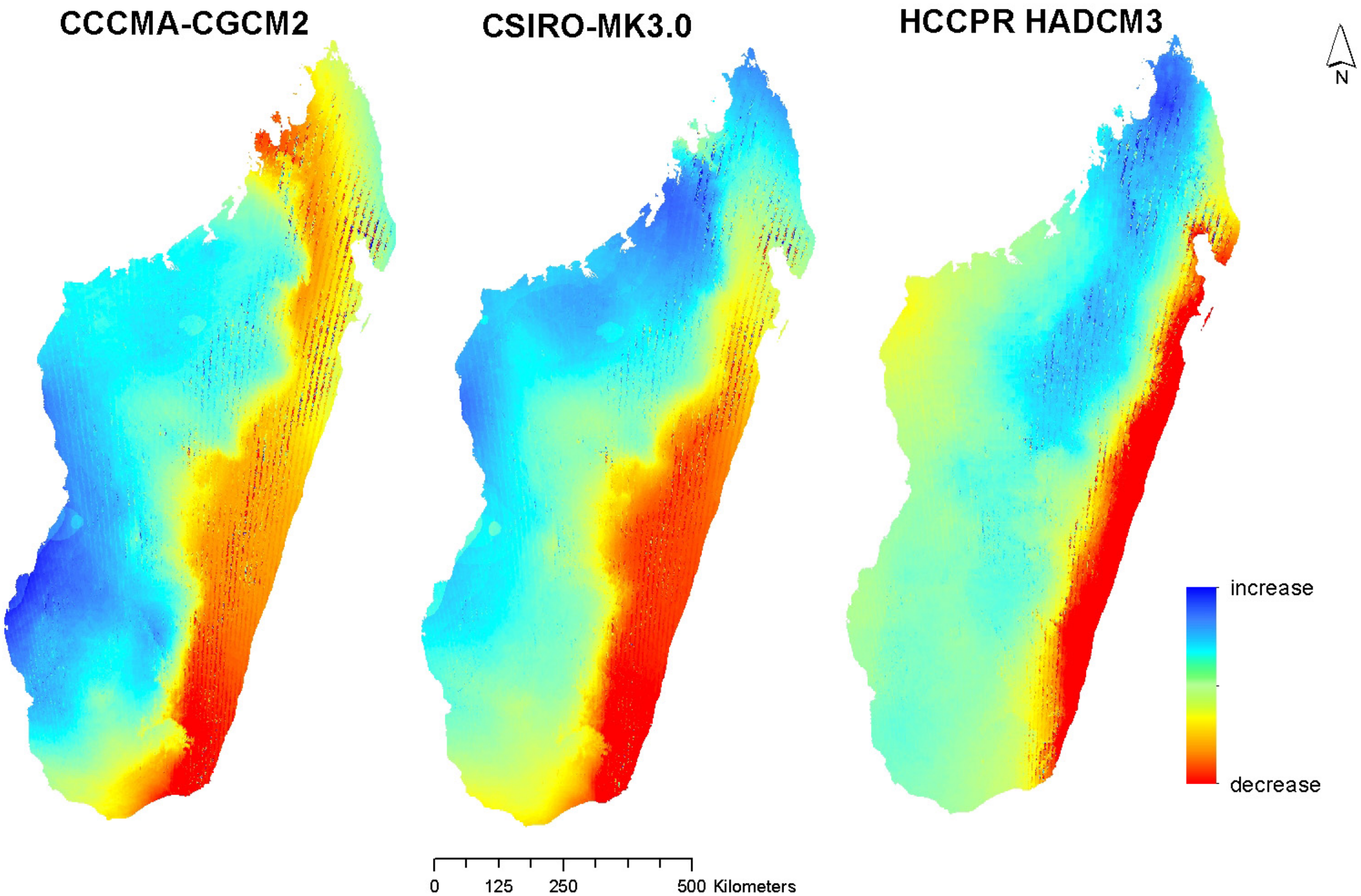

Fig. 8: Annual precipitation change under three climate GCMs for year 2050

Supplemental material 1

Nineteen climate variables are coded as follows: (Source WORLDCLIM)

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly*(max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5 - BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in ecological niche modeling (e.g., BIOCLIM, GARP, Maxent). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the It and dry quarters). A quarter is a period of three months (1/4 of the year)

Supplemental material 2

Madagascar rice dataset from 1961 to 2009, Sources FAOStat, 2012

Year	**Production**	**Yield**	**Area equipped irrigation**	**Area harvested**	**Per capita consumption**	**Production per capita**
	Ton	*Ton /Ha*	*x1000 Ha*	*x1000 Ha*	*kg*	*kg / year*
1961	1465000	1.82	300	804	133.37	280.33
1962	1552000	1.81	300	857	180.83	289.93
1963	1559000	1.83	300	850	157.70	284.23
1964	1648080	1.93	300	854.76	199.57	293.15
1965	1589350	1.87	330	848.99	175.26	275.79
1966	1602800	1.66	330	962.96	177.39	271.29
1967	1706400	1.74	330	981	181.91	281.68
1968	1796500	1.78	330	1008.5	191.34	289.11
1969	1844000	1.88	330	980.35	178.92	289.16
1970	1945900	1.95	330	997.05	186.53	297.27
1971	1893000	1.90	350	997.15	181.62	281.57
1972	1923600	1.89	350	1017.85	175.50	278.54
1973	1913300	1.82	390	1053.2	168.94	269.59
1974	2013450	1.89	426	1063.52	180.15	276.04
1975	1972100	1.83	465	1078.21	166.04	263.02
1976	2042500	1.92	500	1063.92	182.62	264.92
1977	2067270	1.76	538	1175.27	192.96	260.72
1978	1922000	1.70	575	1133	169.51	235.74
1979	2044940	1.76	610	1163	177.23	244.06
1980	2108910	1.76	645	1199	179.10	245.11
1981	2011480	1.70	682	1185.33	186.20	227.83
1982	1969910	1.66	718	1188.1	169.43	217.57
1983	2147000	1.81	755	1189	184.62	231.26
1984	2131100	1.82	790	1170.1	162.96	223.76
1985	2177680	1.84	826	1183.52	169.36	222.71
1986	2230210	1.88	900	1187.57	154.26	221.96
1987	2178000	1.98	900	1098	154.28	210.80
1988	2149000	1.93	900	1111	142.21	202.13
1989	2380000	2.08	1000	1146	142.07	217.45
1990	2420000	2.08	1000	1165	142.91	214.67
1991	2342200	2.05	1000	1140	123.63	201.65
1992	2450000	2.09	1087	1174	140.59	204.66
1993	2550000	2.08	1087	1227	140.91	206.63
1994	2357000	2.07	1087	1139	126.92	185.23
1995	2450000	2.13	1087	1150	123.39	186.72

1996	2500000	2.19	1087	1140	125.71	184.76
1997	2558000	2.17	1087	1176.8	122.34	183.33
1998	2447000	2.03	1087	1203	113.79	170.10
1999	2570000	2.13	1086	1207.5	128.01	173.33
2000	2480470	2.05	1086	1209.3	125.50	162.39
2001	2662470	2.20	1086	1212.65	119.07	169.26
2002	2603970	2.14	1086	1216.02	120.32	160.84
2003	2800000	2.30	1086	1219.4	118.57	168.10
2004	3030000	2.45	1086	1238	129.41	176.87
2005	3393000	2.71	1086	1250	131.77	192.63
2006	3485000	2.70	1086	1291	132.56	192.49
2007	3000000	2.46	1086	1220	134.33	161.26
2008	3914200	3.06	1086	1280	125.79	204.81
2009	4005250	2.99	NA	NA	NA	10938.78

Chapter III

Human dimension of conservation planning: the case of Madagascar

Summary

Recommendations from multiple conservation planning efforts have resulted in the current locations of reserves in Madagascar, based exclusively on species habitat and important conservation sites. However, socioeconomic cost of the reserve network has received little to no attention to date. I used a systematic conservation planning framework to identify a cost-effective reserve network for Madagascar. I considered habitat for 327 species of plants and animals and 7 important conservation sites as biodiversity surrogates, and threat and vulnerability of species habitat to alternative land uses as costs to systematic conservation planning. I developed cost-layer maps from current rice field cultivation, fire occurrence data, and deforestation data. I also considered suitable land for rice field cultivation under scenarios of future climate change to assess the likely persistence of the selected reserve network. My results show that at the national level, inclusion of costs in systematic conservation planning did not drastically change the design of the current reserve network. The effect of including costs may be more pronounced at the regional scale. My results were inconclusive with regards to taking into account shifting costs resulting from future climate change. I conclude by giving recommendations regarding new reserve areas regarding the government priority for setting up additional conservation areas.

Introduction

Systematic conservation planning is a quantitative and transparent method for selecting reserve networks given explicit objectives and goals (Margules & Pressey 2000). This approach was developed to have an efficient and scientifically repeatable solution when designing reserve networks. The usual goal of systematic conservation planning is to select sites of high biodiversity value at an efficient cost. An extensive body of literature has considered conservation planning in various regions of the world, and includes the conceptual discussion of identifying elements of biodiversity to protect, and the concrete spatial prioritization of conservation at the global and regional level. (e.g. Kark et al. (2009), Kremen et al. (2008), Stewart, Noyce, and Possingham (2003)).

Madagascar is a biodiversity hotspot (Mittermeier et al. 1998), and is home to an estimated 5% of the world's fauna and flora (WWF, 2011), more than 86% of which are not found elsewhere in the world. Madagascar has a high level of species endemism but also has many endangered habitats because of human actions such as deforestation. While there is continuous loss of species habitat due to deforestation, the annual rate has decreased relative to a decade ago (Harper et al. 2008). In response to the observed human threats, coordinated efforts between international and national organizations have taken place to set up a reserve network for biodiversity protection. A steady increase in the area protected in Protected Areas (PA) has been observed since 1991 (Fig. 1) and as of 2012, Madagascar lists 79 terrestrial PAs totaling a little less than 5.4 million hectares. An additional 71 tentative PAs totaling 1.4 million hectares are awaiting official change from a temporary to a permanent status.

Conservation planning efforts have been in place in Madagascar for decades, mostly for single taxonomic groups and at various individual sites (Putnam 1996; Fisher 1997; Smith et al. 1997; Kremen et al. 1998; Schmid 2000) until (Kremen et al. 1999)proposed a plan for a national reserve network based on a multi-taxonomic approach (as opposed to single-taxon). Most of the recently named PAs (Rebioma 2009) are the result of recommendations from Kremen et al.,(2008) . One concern is that this plan, like many other conservation plans developed around the world, emphasized biodiversity protection but did not include differential land costs and vulnerability and threat to species habitat across land areas (Naidoo et al. 2006). Thus critics noted the lack of socioeconomic cost input in the conservation plan, and suggested the plan risks conflicts with Madagascar's population, which is highly dependent on natural resources (Bode et al. 2008a). More recently, another study attempted to integrate biological, socioeconomic, and ecosystem service knowledge to prioritize key biodiversity areas (KBA) in Madagascar (Rogers et al. 2010). While this study ranked existing KBAs according to human related threats and economic importance of ecosystem services in the KBAs, integrating human related threats and mapping them across space was only done after identification KBA; their framework simply ranked known important sites by going through various classification of socio-economic variables.

Integrating socioeconomic costs as spatial layers in the early phase of conservation planning can help avoid selecting habitats most vulnerable to human land use change, while at the same time efficiently selecting important areas for biodiversity protection (Williams et al. 2003; Naidoo et al. 2006; Richardson et al. 2006). Vulnerability, a proxy for cost (Naidoo et al. 2006), can be measured in terms of the biodiversity value of an area that would be lost if conservation is not undertaken. Vulnerability can also be a correlate of cost (Wilson et al. 2005), thus a measurement of the likelihood of an area being degraded (e.g. via land use change or habitat degradation) over time. Therefore, a good understanding of vulnerabilities (and/or costs) is a key to realistic site selection. Many studies have demonstrated that threats and socioeconomic costs are not homogenous in time and space (Williams et al. 2003; Naidoo et al. 2006; Cameron et al. 2008) and have suggested that incorporating their spatial distribution is critical in order both to reduce the overall economic cost of reserve design, and to reduce the vulnerability of habitats to land use change. Some authors contend that accounting for socioeconomic costs could improve confidence in setting up conservation priorities and could more effectively protect biodiversity, even in the absence of biodiversity data (Bode et al. 2008b).

In this study, socioeconomic costs refer to the costs of avoiding conflict between human and species habitat. The method I used to assess socioeconomic costs is based on the analytical framework of Wilson et al. (2005). I took into account the characteristic of species habitat and other spatial environmental variables; built a quantitative model of the current threat or vulnerability; and then, projected the modeled costs by using future climate scenarios. The cost layers included: (a) a model of deforestation, which threatens the remaining forest block; (b) a model of rice field suitability that I refer to as an agricultural suitability map, and (c) a density of fire over the past 10 years.

Future climate change adds another layer of complexity and uncertainty to conservation planning because of the need to accommodate species adaptation while at the same time addressing future human needs. Climate change model projections in Madagascar have predicted an overall consistent increase in temperature between 1.1^{o}C to 2.6^{o} C, for the period 2046-2065 across the country. These projections also suggest highly variable rainfall patterns throughout different geographic locations and during different seasons (Tadross et al. 2008). At the regional level, the effect of climate change has major implications for species distribution. Many species' habitats are now restricted to small areas of natural forest. Given that many species' habitat has already been lost or fragmented and that species may need to shift to follow their climate niches, protecting corridors between forest fragments is of paramount importance (Hannah et al. 2008). However, these conservation actions are often in direct conflict with human needs.

This research re-examines the effectiveness of the reserve network proposed by Kremen et al. (2008), by looking at the possible conflict in the existing protected areas given the integration of various costs into the process of network reserve selection. After looking at the possible changes needed in the design of current conservation areas in Madagascar when introducing cost to conservation planning, I also investigate what changes would be needed to take into account the effect of future suitable agricultural land (under future climate change scenarios) in planning the reserve network, and provide recommendations for the expansion and priority setting of new PA priority sites.

Materials and Methods

Marxan, a decision support tool

I choose Marxan to identify areas that efficiently meet targets for a range of biodiversity features at minimal cost. Marxan is a decision support tool for reserve selection (Ball et al. 2009). To meet targets at the most efficient cost, the Marxan algorithm runs through iterative processes of random planning unit (PU) selection based on the principle of species complementarity (maximizing the total number of species protected across the network, rather than the species richness in any given portion of the network). Marxan allows a number of process options to be executed. The first one is the “free option” where initial PUs to be selected are not restricted. The second is the “locked” option where PUs can be “locked in” or “locked out”. Locking factors force Marxan to always include or always exclude the specified planning units in the final selection. The last option is “seeded” (term coined by (Meerman 2005). The seeded option gives priority to a set of PUs; however, these PUs are not guaranteed to be part of the final solution. This last option can be used to check how current PAs perform to fit a given conservation goal (or set of target).

To select a set of PUs, Marxan minimizes the sum of the following objective function:

$$\sum \textit{PU Cost} + (\textit{Boundary Length Modifier} * \sum \textit{Boundary Cost}) + \textit{Species Penalty Factor}$$

Boundary Length Modifier (BLM) and Boundary Costs (BC) are factors that control the spatial aggregation of selected PUs by altering the clustering or dispersion of the final solution. The Species Penalty Factor (SPF) is the penalty imposed on conservation features for not meeting the species conservation target. In general, Marxan minimizes this function to minimize the cost of the reserve network, while minimizing the number of species whose targets are not met without creating an overly fragmented network (Ball et al. 2009).

Conservation features

I used models of species distribution patterns and key biodiversity area (KBA) as the biodiversity inputs to Marxan. All data in this study came from the previous study of Kremen et al., (2008) and the Rebioma Atlas (2009). Species niche modeling was previously carried out for some species based on existing occurrence data by using maximum entropy techniques (Maxent software) and the results were validated by taxonomic experts for each group (Kremen et al. 2008). Expert opinions were taken into consideration to create possible home ranges for the species when occurrence data were not available(Rebioma 2009). I started with 1140 species and 10 conservation sites as biodiversity surrogates, a subset of the 2315 species that had a mapped habitat from previous work. The 1140 species were made up of mainly flora with a total of 642 species and the remaining were made up of fauna; and were distributed in 6 taxonomic groups (see Table 1 for summary and appendix for details). I input a total of 327 species and 7

KBA into Marxan after a species gap analysis. Details of species taxonomic distribution and respective target areas are in the appendix. Similarly, I conducted a gap analysis on 10 KBA that were identified by a group of experts as ecologically important areas, particularly for vegetation (Eken et al. 2004). The gap analysis revealed that 7 of these KBA occur, inside of the current protected area network but targets were not met. Thus, these 7 KBA were also included in the analysis.

Development of cost layers

Cost refers to assessed vulnerability in the landscape for each PU and is expressed in probability values between 0 and 1 across the landscape. A planning unit with a cost of 1 has a high value and is to be avoided, while 0 is the least costly selection. Three cost layers were constructed based on: a model of suitable land for rice fields, density of fire occurrence, and a model of probability of deforestation. Both the maps of rice field suitability (Fig. 4 in Chap. 1) and of probability of deforestation were produced using spatially-explicit maximum entropy models, using the software Maxent. Maxent software is a machine-learning algorithm that uses presence records and random background data to compute the probability of occurrence in a defined geographic range (Phillips et al. 2006; Elith et al. 2006). The fourth cost layer was a projection into the future of rice field suitability under three future climate global circulation models (Chap. 1, Fig. 7). Data sources for development of cost layers are listed under Table 2.

I created a map of deforestation vulnerability (Fig. 2c) resulted from a Maximum Entropy model based on current and past deforestation for Madagascar (see Appendix). I then used this map as a cost surface to avoid regions with higher deforestation threat. Land is deforested in Madagascar principally for slash and burn agriculture (Marcus 2001; Aubert et al. 2003; Gezon 2007), and thus the deforestation map can be considered to represent not only the vulnerability of forest habitats, but also the economic potential of that land for cultivation (i.e. the opportunity cost). Modeled deforestation only identifies threatened forested regions, thus giving a virtual low cost to regions where there is no more forest.

I compiled 10 years of fire occurrences generated from MODIS data (Justice et al. 2002; Morisette et al. 2005) to track burn locations in Madagascar (Fig. 2d). Fires can be characterized in term of area of coverage, intensity, and frequency of burn. However, I only utilized the occurrences to create the fire density map, which shows only the vulnerability of habitat to fire rather than the frequency or the intensity components. Although frequency and intensity are important attributes of fire, I did not have this information because existing data are only point center of occurring fires (as opposed to spread and heat intensity) and lacks these attributes. Fires are used mainly for agriculture management, including slash and burn farming and rangeland management (Kull 2002a, 2002b). Fires represent a major threat to different ecosystems: in the dry habitat of the western savanna (Bloesch 1999), in the mountain schlerophylous forest and over most of the forested area in country (Kull 2000, 2002c), especially in the eastern humid forest (Lowry, 1997). Since fires in Madagascar generally reflect an economic land use, modeling their probability of occurrence also generates an opportunity cost surface.

I created a spatially-explicit model of land suitability for rice fields to use as a cost surface (Fig. 2a), using data on the currently cultivated fields and their climatic and geological characteristics to identify potential areas for rice cultivation (Chap 1). I refer to this surface as suitability for irrigated crops. A second set of maps was produced by projecting the current suitable rice fields to a future climate (Chap. 1), indicating the future areas for land conversion/vulnerability. Irrigated rice fields alone have contributed up to10,000 hectares per year of natural habitat conversion in the last 50 years. Similar to other land usages, land transformation to rice fields directly competes with species habitat. Further, lands suitable for cultivated crops have an economic value (opportunity cost) which should ideally be minimized in conservation planning.

Population density as a locking factor

Madagascar has an estimated population of 21 million based on population density data from Landscan (Bright et al. 2009). I used this population data to identify areas of high population density, and I locked out PUs (totaling 3675 km2) that contains large towns with 375 habitants per km2 or above. I locked these out in order to avoid direct conflicts between the reserve network and major cities, roads and other large human dominated landscape features.

Gap analysis

I started by conducting a simple gap analysis for the 1149 species and 10 KBA. I overlaid the following layers: current protected area, predicted distribution of species, map of KBA, to determine how much of the biodiversity data is featured in the current PAs. I then calculated the conservation targets for each species or key biodiversity area. I set up the amount of species target (habitat size to be preserved) per species based on a logarithmic curve calculation that gives high targets to species with low range size and vice-versa (Rodrigues et al. 2004). Thresholds were then applied as follows: (1) species with a range less than 200km2 were set to 100% habitat as target to be preserved while (2) wide spread species that occupy more than 10,00km2 has only of 10% habitat size as target. The same methodology was also applied to the key biodiversity areas. Next, I assessed the coverage of each species or KBA compared to its target to identify which species or KBA were already adequately represented with the current PA network excluding any PAs with temporary status. 327 species had area targets that were not met by the existing PA network along with 7 KBAs.

Framework for analysis

Next, using a 1km square grid, I divided Madagascar into 593,363 individual planning units (PUs). Each PU had biodiversity values, a locking factors value, and 4 cost attributes corresponding to our models of probability of deforestation, fire and suitability for rice cultivation (current or future). I ran a total of 11 scenarios with 100 replicates each. I input distribution data for 327 species and 7 KBAs into Marxan as biodiversity features data. Each Marxan scenario runs 1 billion annealing iterations and only the best score was kept. The optimal results of each iteration were compiled to create a selection frequency. This selection frequency is sometimes referred to as summed irreplaceability, if it is 1, the PU must be included in order to meet targets, whereas if it is a low value, many other sites could be selected instead to meet targets (Ball et al. 2009). The data analysis consisted of comparing different scenarios and identifying the added effect of socio-economic costs. I utilized two baselines for comparison:

reserve selection based exclusively on biodiversity features, and the current protected area. Different scenarios were set up to provide specific comparisons as follows:

1- Scenario A1 selects the location of the priority area without considering cost. This scenario provides the first baseline which is a free (unconstrained) solution that provides the optimal solution for reserve selection based solely on biodiversity, i.e. without taking into account existing protected areas or costs.
2- For all B scenarios (seeded option), the existing PAs are provided as the first choice for Marxan to select but there is no guarantee that they will be included in the final solution. By comparing the cost to no cost within this scenario, we can identify the spatial shift of the selected areas caused by cost.
3- All C scenarios have current protected areas locked in (second baseline, includes 61682 PUs forced into the solution). These scenarios identify additional potential areas for the extension of PAs in Madagascar.

Within the B and C scenarios, I successively ran Marxan with each of the 4 different cost/vulnerability surfaces, leading to five scenarios each in B and C and a total of 11 scenarios (See Table 3).

I looked at the spatial pattern of selection frequency of all scenarios described in Table 3. For each result, I ensured that the species targets were met. I utilized the selection frequency of 100 runs to identify the similarities and differences between the scenarios in order to assess the effect of socio-economic costs on the patterns. To have a single layer of selection based on cost I summed all the results from scenario B (2, 3, and 4) to create a percent of site selection. I did the same operation for the locked option (scenario C2,3 and 4)

Calibration of Marxan runs

Prior to running each scenario, I calibrated all BLM and SPF parameters and number of iterations by scenario. According to the Marxan handbook, it is recommended to set BLM first, then SPF and finally the iteration number (Ardron et al. 2010). The BLM was set to the lowest value of 0 and then incrementally increased until spatially consistent solution were achieved. Each final BLM value is indicated in Table 4. For the locked option, an acceptable compactness was achieved around selection of 135,000 PUs while for the seeded option, acceptable compactness was achieved at only 70,000 PUs. The reason for the difference in BLM between these two scenario types is that locked scenarios select additional areas outside of the existing PAs, whereas seeded scenarios select an equivalent area to that of the current PAs. Next, we altered the SPF to meet all biodiversity targets. A small SPF value may result in both inconsistency of spatial selection and high variation in the total cost. All eleven scenarios were given the same SPF value, however, as altering SPF value did not turn out to impact the proportion of targets met. Our iteration number was set to 1 billion, which is the highest value that produced the least amount of variation in the total score of the objective function. A large iteration number can noticeably slow down the process of site selection, sometimes without any specific gain in cost efficiency of the selected PUs. Each of the 11 scenarios were calibrated for BLM, SPF and iteration number independently.

Results

Biological importance

I selected different areas for conservation based on a spatial prioritization that used the distribution of 327 species and the location of 7 KBA. I obtained this list by conducting a species gap analysis in the current protected area network in Madagascar. By running the free option where there is no cost constraint, (scenario A1) we identified different zones that are more and less important for conserving these species and KBAs (Fig. 4). This result served as a reference to look at any spatial pattern changes with different scenarios of vulnerability. Fig. 4 shows that most of the selected units lie outside of existing protected areas, confirming that the considered biodiversity data resulted from an earlier gap analysis. A large section of current PAs were not selected by this spatial prioritization, while only 25% of current PAs had selection frequency more than 90%.

In the next scenario (B1), I used a seeded spatial prioritization, in which Marxan was constrained to select from existing PAs first, but was then free to choose other areas in order to meet unmet targets. The result (Fig. 5) shows greater compactness, but is similar to the result of the free option. The result confirms that many PAs either do not include critical habitat for the ensemble of biodiversity data or they are redundant areas.

To understand the effect of the socio-economic costs on the spatial prioritization, we needed to know their spatial distribution (see results presented in Fig. 2). The highest suitability value for agriculture was mostly around rivers, wetland and water bodies. This particular cost surface is fairly distinct from the gap species' habitats, with the exception of some locations in the wetland areas. Conversely, the probability of deforestation map showed highest values inside already fragmented forest. The threat of deforestation is much lower in the southwest than in the eastern forest block. The large block of high elevation forest in the north also has a low probability of deforestation. Low probabilities of deforestation are also observed in a large forested area in the southern plateau of Madagascar. It is clear that the edges of forested areas are the most threatened by deforestation, and Marxan has avoided selecting those areas (Fig. 6).

To compare the differences between the cost and no cost scenarios, I combined the results of B, 2, 3 and 4, and compared it with B1 (Fig. 5), focusing on the large blocks of forest in the North for better resolution. Notice that the seeded option places meets targets by selecting some regions inside the PAs and then selecting regions outside of them for a better options that avoid costs. This comparison shows that while selection of best PU is more restricted than the no cost B1 scenario (as expected), it did not create major shifts in selection patterns. The same trend is also observed when comparing cost and no cost scenarios for the locked option within the same geographic region (Fig. 6). The locked version selects all PAs first before moving outside to meet the biodiversity target. Again, I observed a more restrictive effect of the cost layer rather than a complete shift to a different location.

Regarding the cost associated with climate change effects on irrigated agricultural land, I compared scenario B5 to B2 and scenario C5 to C2. I found no major change in the spatial pattern. Scenario C5 appeared to be more restrictive in southern and western Madagascar (Fig. 7). Lastly, I compared the priority zone previously selected by the Protected Area System of

Madagascar (SAPM) with the C (2,3,4) scenario results. Only one out of 18 zones overlapped with the results representing the irreplaceability surface (Fig. 8).

Discussion and conclusion

Addressing socio-economic concerns

This study investigated the effect of adding socio-economic costs into the selection of reserve areas, which has never previously been done in conservation prioritization for Madagascar (Bode et al. 2008a; Kremen et al. 2008 - response to Bode). Socio-economic costs included spatially-explicit variables that proxy for key human-induced land use changes including rice field suitability, burn frequency, and probability of deforestation. For Madagascar, conflicts between local people and protected areas manifest themselves in different ways. They can range from the simple rejection of a park boundary that leads to land encroachment to more aggressive actions due to anti-PAs sentiment such as intentional burning (Kull 2002a; Gezon 2007). There are no Marxan results that can resolve these conflicts. Instead, results from systematic conservation planning can only inform and help stakeholders in addressing specific management decisions. At best, these results can be used as a guide for where to focus future conservation efforts, and which areas to avoid. Further, in identifying new areas for biodiversity protection, proposing a reserve network is the beginning rather than the end of the work, and the final solution should result from negotiations between all stakeholders (Knight et al. 2006).

When comparing scenario C1 to C(2, 3, and 4) and scenario B1 to B(2,3, and 4) we noted that the introduction of costs did not fundamentally change the design of the reserve network. Despite the fact that selected reserves are more restricted when costs are taken into account (as expected due to additional constraints), we did not observe any major shifts in locations of areas selected in either locked or seeded options. However, because of constraints due to adding costs, some the narrow-ranged species, especially among fishes, were not selected in any high cost areas. The effect of cost constrains may be more problematic for narrow-ranged species, which in fact constitute the majority of the biodiversity that we considered in this study (Fig. 3.Another explanation of the dismissed species range is that by setting goals for large scale conservation (i.e. at national level), we may inadvertently ignore some important populations at the local scale (Kark et al. 2009).

Technical issues

I chose 1km2 as the scale of the analysis and size of the PU. A larger planning unit may overlook the many small fragmented forests which dominate Madagascar's landscape now, and thus a larger unit might not be ecologically meaningful. In addition, larger PUs would have skewed the PA size, the country area and the biodiversity habitat area by artificially changing the edge shape and the boundary length. With a larger PU, locking in/out PAs can become problematic, because any PA that overlaps in the slightest degree with a PU will cause that PU to be locked in/out. However, smaller PUs require detailed information that is truly at that scale (as opposed to downscaled), which is costly to obtain. Further, producing detailed results requires more computational time and power, since Marxan relies on an appropriate iteration number to produce meaningful results. Thus selection of the PU size requires balancing cost versus accuracy considerations.

In this work, I did not distinguish between species status (i.e. endangered, threatened, or not listed as a concern),within the analysis, but instead translated this status into biodiversity targets, which are more precise (Rodrigues et al. 2004). By so doing, the SPF value should reflect the species status and priority for conservation. For instance, we needed to make sure that a critically endangered species' habitat is prioritized over a more common species' habitat.

Appropriate analysis in Marxan, as in any scientific analysis, depends on the quality of the input data. Marxan is a decision support tool that is transparent and repeatable. However, the process is complicated, requires high technical capacity, and can be very time consuming, thus some researchers are advocating developing simpler decision support tools for conservation planning (Randriarimalala 2006; Rogers et al. 2010). This tool may therefore be less accessible for utilization in on-the-ground conservation planning in Madagascar.

Reserve selection

As of 2012, Madagascar has about 10% of its land under protection. In the early stage of conservation actions, about 64% of the PAs were under the IUCN categories II , a National Park, and IV, a habitat management area (Rasoavahiny et al. 2004). Many of previous reserves were placed in protection without consideration of possible human conflict. However, since 2003, the majority of the newly created PAs fall under category V, a protected landscape that requires a balance between people and nature (10 PAs), and category VI, PA with a sustainable use of natural resources (8 PAs), where the reserve management requires participation from the community and the goal of the reserve or park is not solely for biodiversity protection but also for human well-being. This shift is simply a result of the call for more people-oriented approaches (Borrini-feyerabend & Dudley 2005), that require alternatives to strict conservation. By explicitly integrating costs into conservation planning, specifically considering human land uses and needs, it may be possible to better map and design the reserve network to accommodate the needs of local people.

The results based on current data and habitat vulnerability address the short term ecological goal while introducing future suitable land under future climate scenario is an attempt to look for a long term goal, or the persistence of the reserve network. Our results suggested potential lands for irrigated agriculture under climate change need not greatly influence the choice of biodiversity conservation areas today. The lack of effect of future irrigable lands may be due to the fact that the distribution of biodiversity considered in this study does not overlap with the predicted suitable agricultural land in the future. The fact that considering this potential threat did not shift conservation priorities suggests that changes in irrigable land due to climate change may not constitute a threat to persistence of nature reserves in the future. Instead, climate change may primarily influence biodiversity conservation through direct impacts on species distributions, since the notable fragmentation of Madagascar's forests may constitute a key barrier to the ability of Madagascar's species to track climate niches (Hannah et al. 2008).

Table 1: Distribution of biodiversity data per taxonomic group

Taxonomic group	**Number of specie**
Amphibians	29
Bird	7
Fish	37
mammals	24
Plant	203
Reptiles	27
Total	**327**

Table 2: Details on data sources

Marxan input	**Description**	**Data type and resolution**	**Data sources**
Biodiversity features	1140 Species of fauna and flora 10 key biodiversity area	Raster grid 30 arc sec (~ 0.86 km)	Kremen et al. 2008 Rebioma Atlas, 2010 (www.rebioma.net)
Costs	Quantitative model to predict paddy rice field suitability (Chapter 1) Rice field suitability under future climate change scenarios (Chapter 1)	Raster grid 92m	FAO 2011; FTM BD 200 WorldClim database / 3 General Circulation Models datasets (Hijmans et al. 2005)
Costs	Density of fire	Raster grid 92m	University of Maryland, MODIS data (Justice et al. 2002; Morisette et al. 2005; de Klerk 2008)
Costs	Model of deforestation threat	Raster grid 92m	Conservation International 1990-2005 forest cover data (Harper et al. 2008)
Status	Existing protected areas Population density from Landscan Global population database	Polygon Raster grid 30 arc-sec (~ 0.86 km)	Rebioma Atlas 2010 (ORNL 2008)

Table 3: Scenario list for conservation prioritization

Option	Scenario	BLM value	Description
A- Free option: no restriction	A1	0.2	Species and KBA
B- Seeded option: large towns are locked out, existing PAs are given priority	B1	0.003	Species and KBA
	B2	0.0001	Species and KBA + potential for irrigated Agriculture
	B3	0.0003	Species and KBA + vulnerability to Fire
	B4	0.0000003	Species and KBA + vulnerability to Deforestation
	B5	0.001	Species and KBA + potential for future irrigated agriculture
Locked option: large cities are locked out, existing PAs are locked in	C1	0.02	Species and KBA
	C2	0. 002	Species and KBA + potential for irrigated Agriculture
	C3	0.0001	Species and KBA + vulnerability to Fire
	C4	0.00003	Species and KBA + vulnerability to Deforestation
	C5	0.01	Species and KBA + potential for future irrigated agriculture

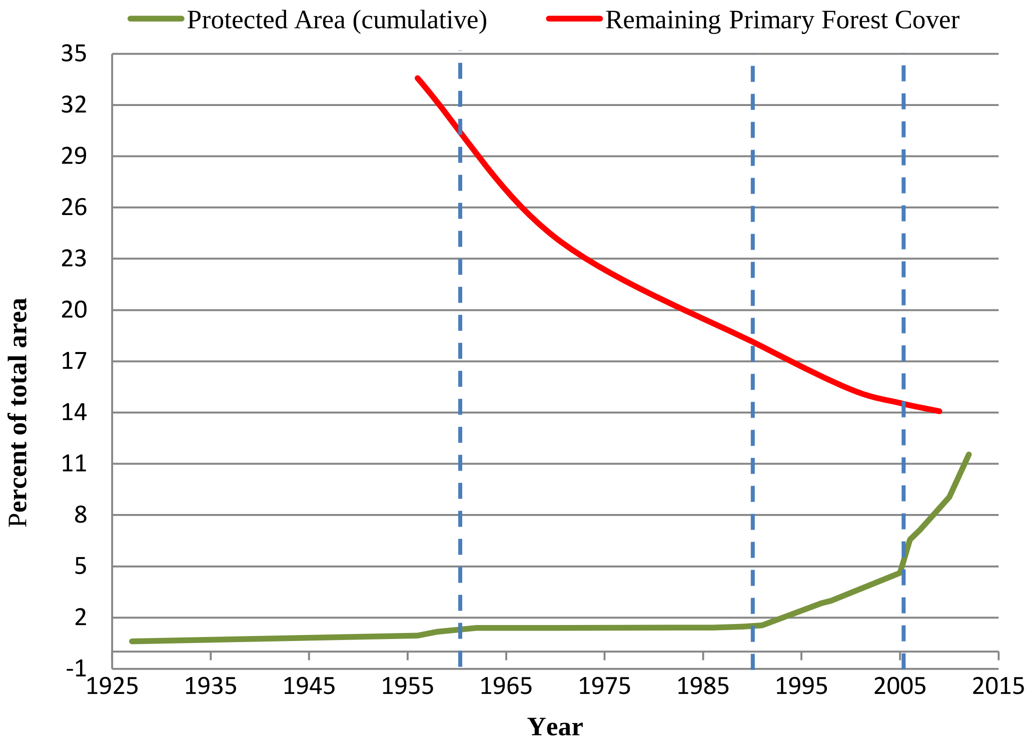

Fig. 1: Protected Areas size and current deforestation. Protected area size in this graph is based on official text of protected areas from the Government of Madagascar (Gov. decrees since 1927). Sizes are calculated based on Randrianandianina et al. (2003), WCS, CI and WWF shape files of current and proposed protected areas. The forest cover change was based on 1955 map Humbert et al. (1965); Faramalala (1995); and Harper et al. (2008). Deforestation Map from Conservation International (dataset available at http://gis.conservation.org), and from the KEW Royal Botanical Garden (http://www.kew.org/gis/projects/mad_veg/default.html) were also used.

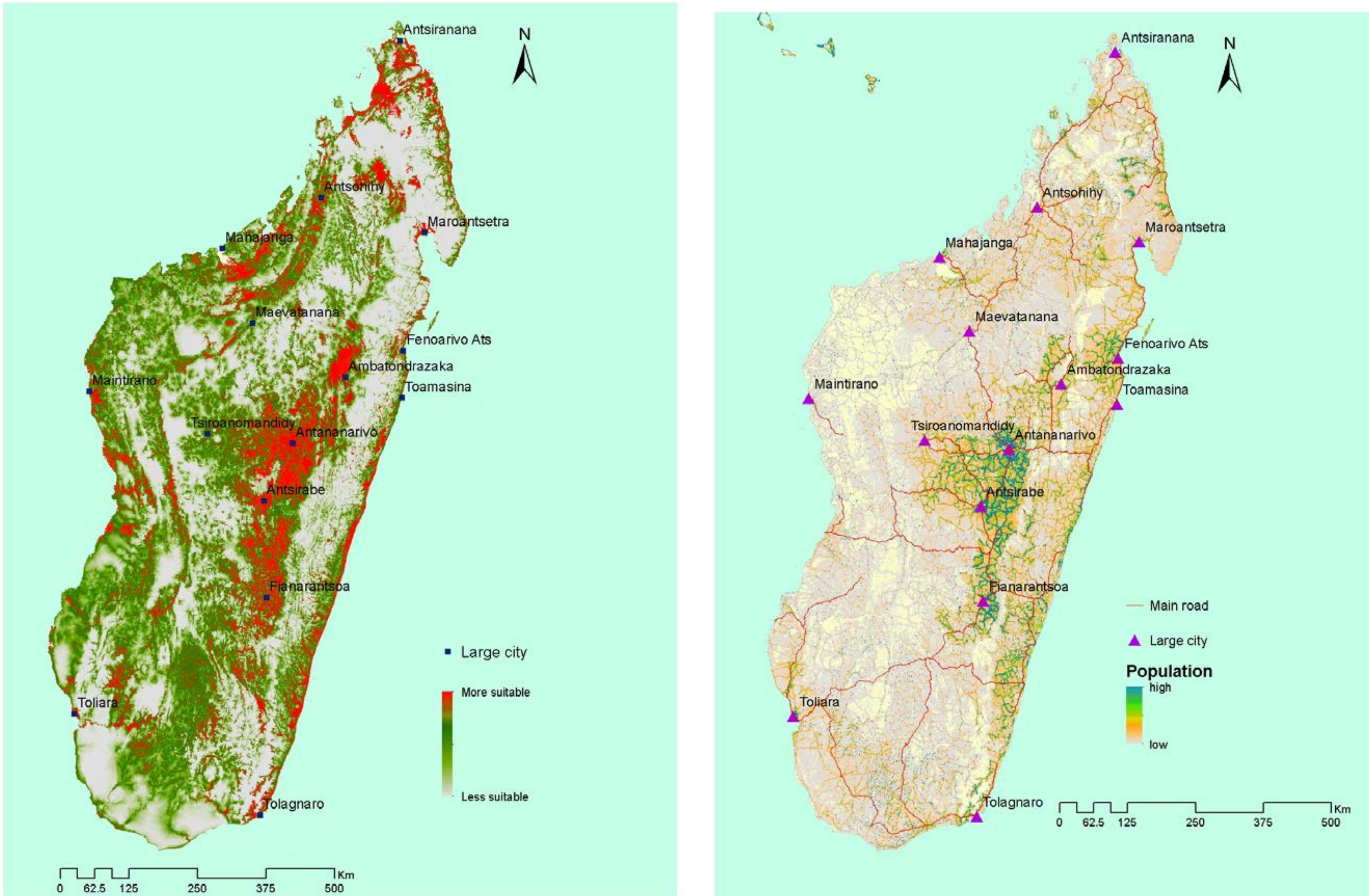

Fig. 2: Cost layers for Marxan input: (a) irrigated agriculture suitability map; (b) population density map

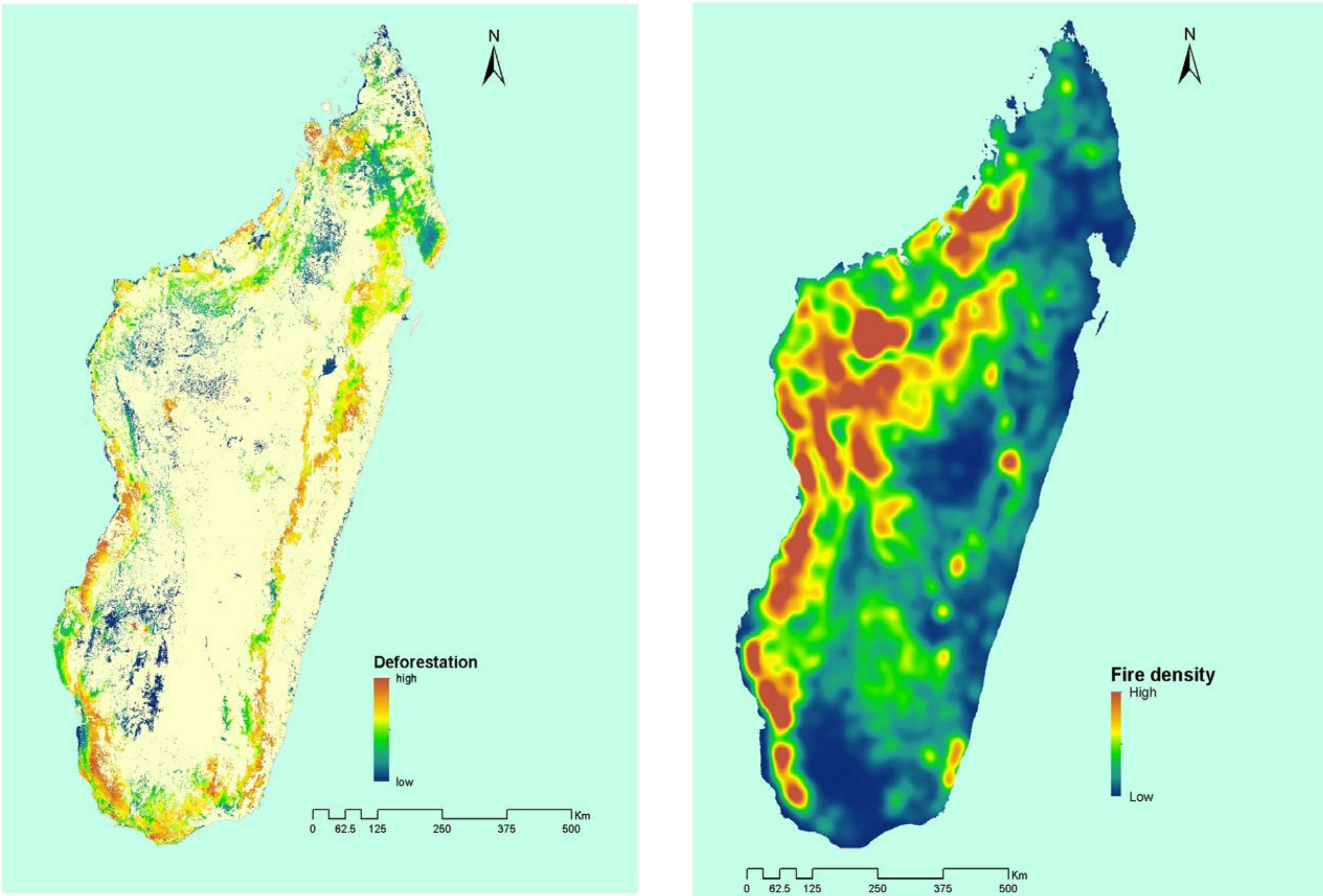

Fig. 2: Cost layer for Marxan input: (c) vulnerability to deforestation, (d) fire density.

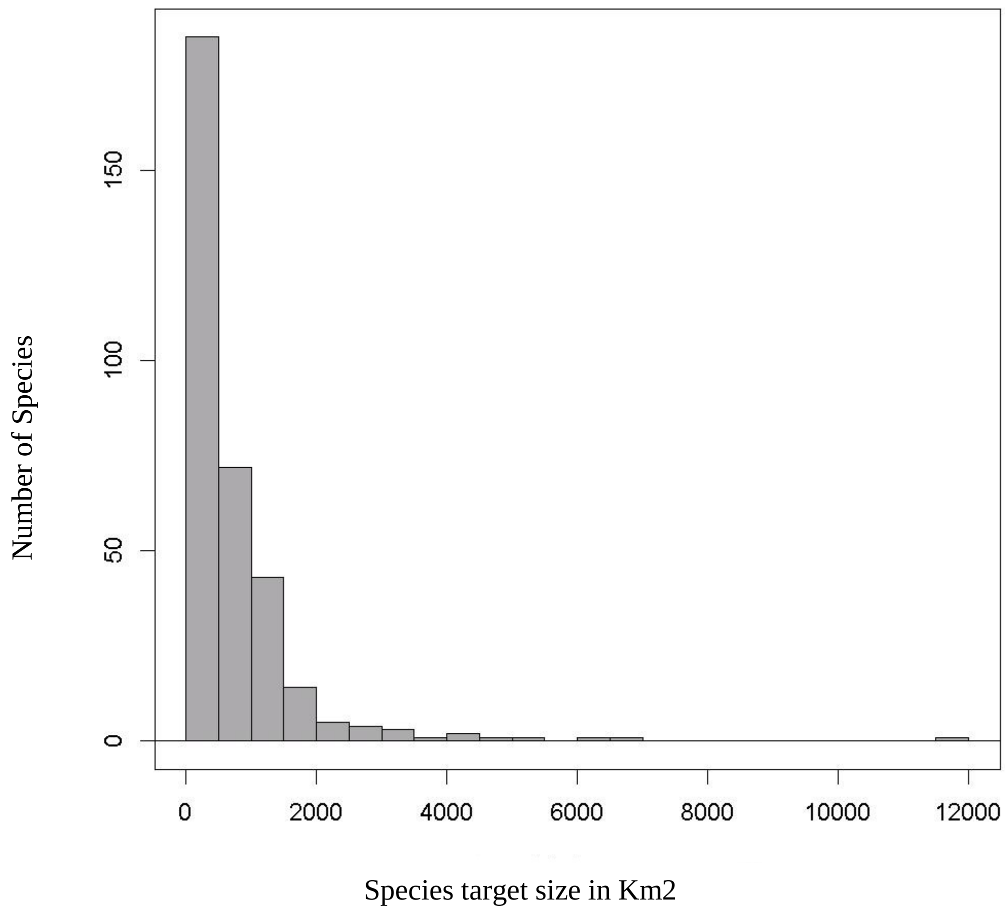

Fig. 3: Biodiversity features and distribution of target sizes

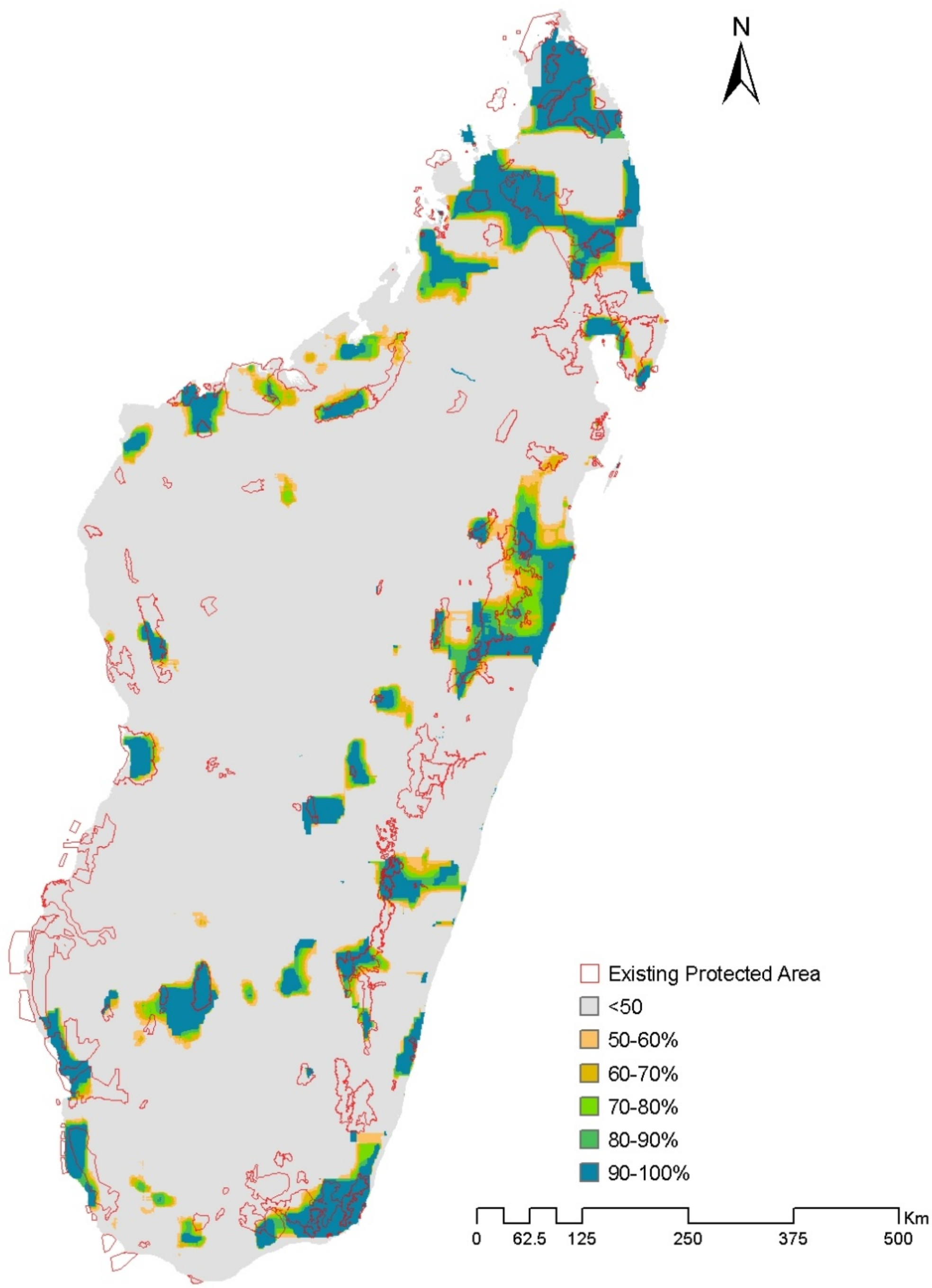

Fig. 4: Selection frequency for scenario A1. Selected areas for gap species and key biodiversity areas, in an unconstrained scenario, overlaid on current protected areas. The color ramp represents PUs selected > 50% of time and above.

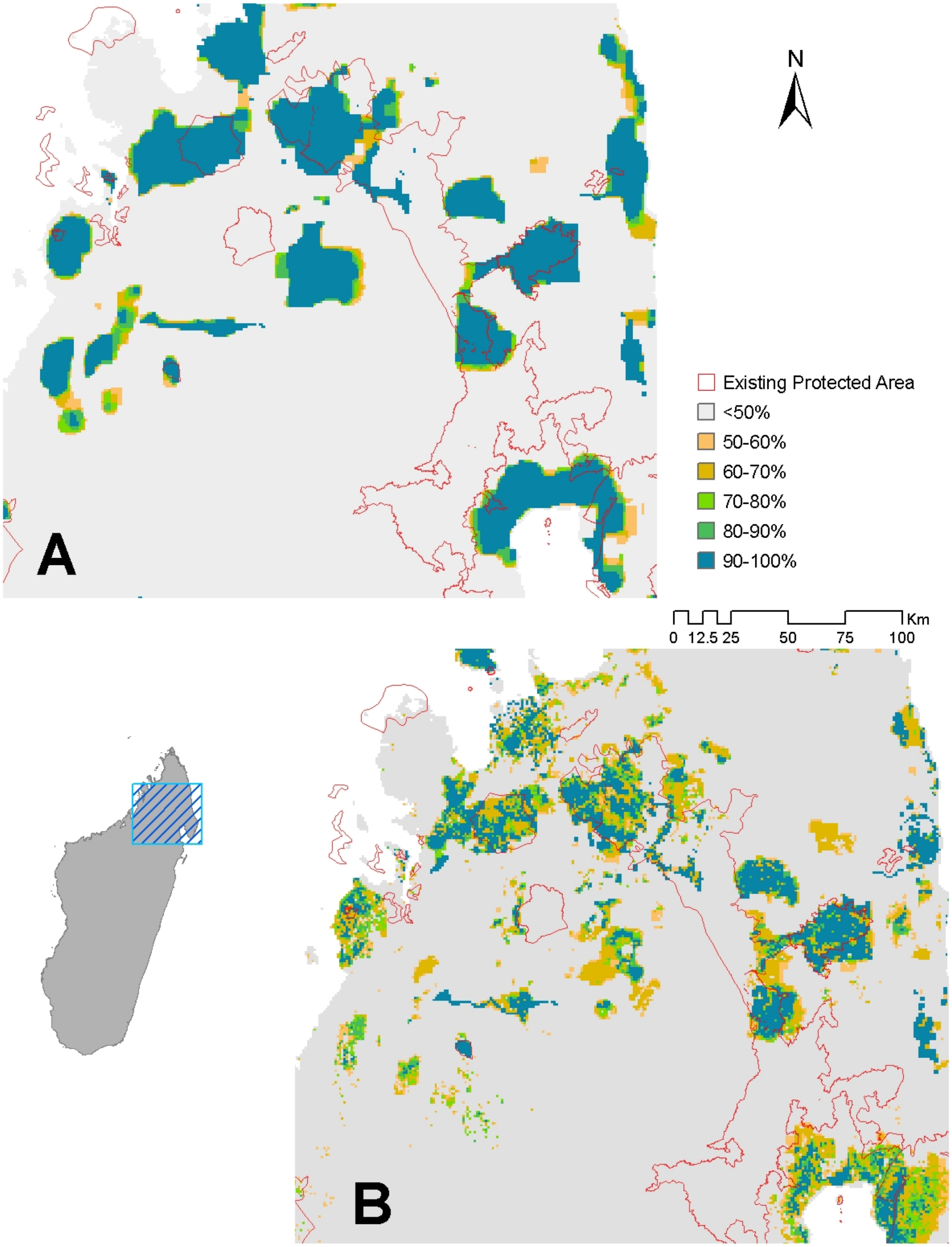

Fig. 5: Comparing no-cost (A) ,and cost (B) scenarios within the seeded option. This region was selected for in depth study because it contains the largest remaining forest blocks in the north. The color ramp represents PUs selected > 50% of time and above.

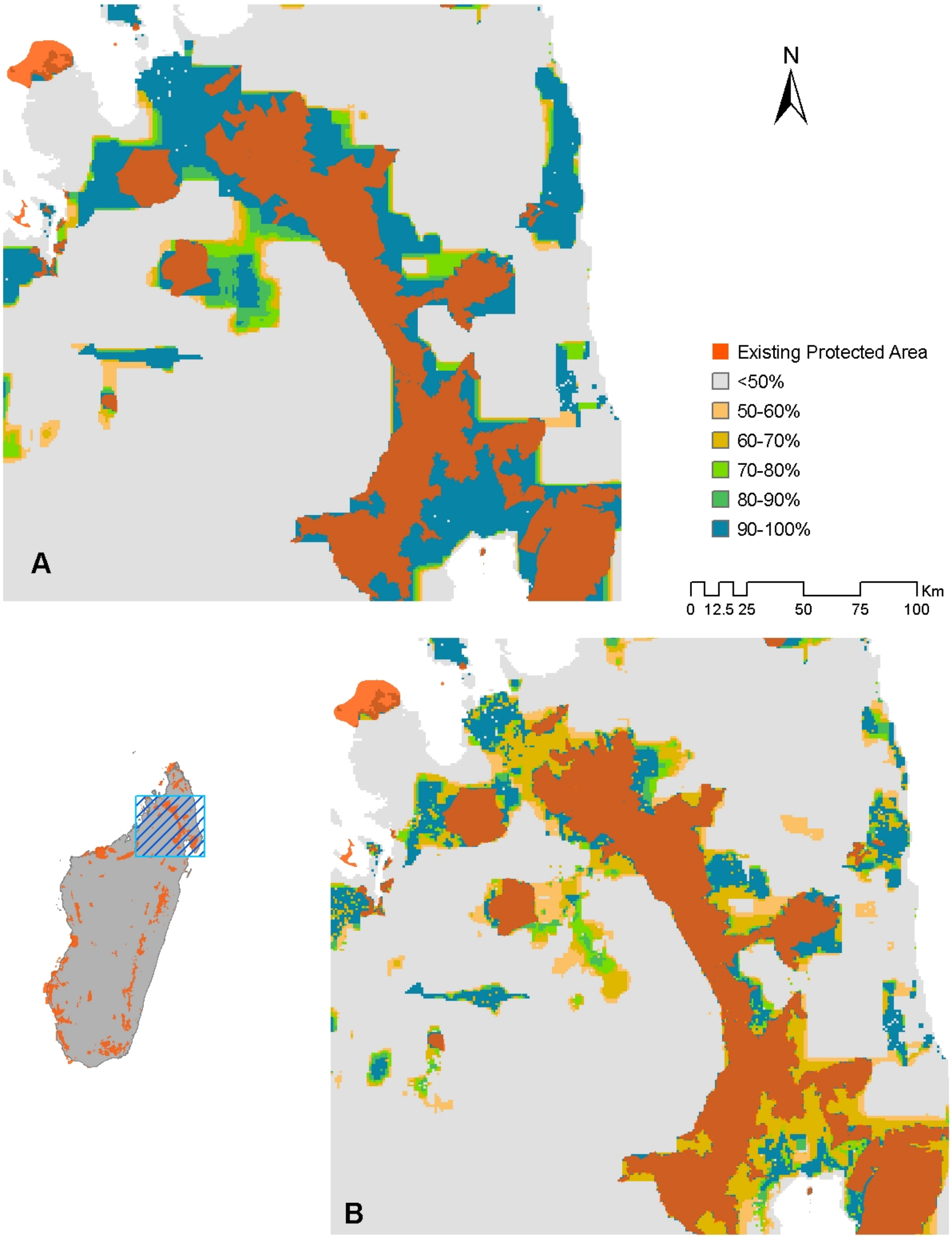

Fig. 6: Comparing no-cost (A), cost (B) scenarios within the locked option. Same region as Fig. 5. The color ramp represents PUs selected > 50% of time and above. Existing PAs are forced into the solution (dark orange color)

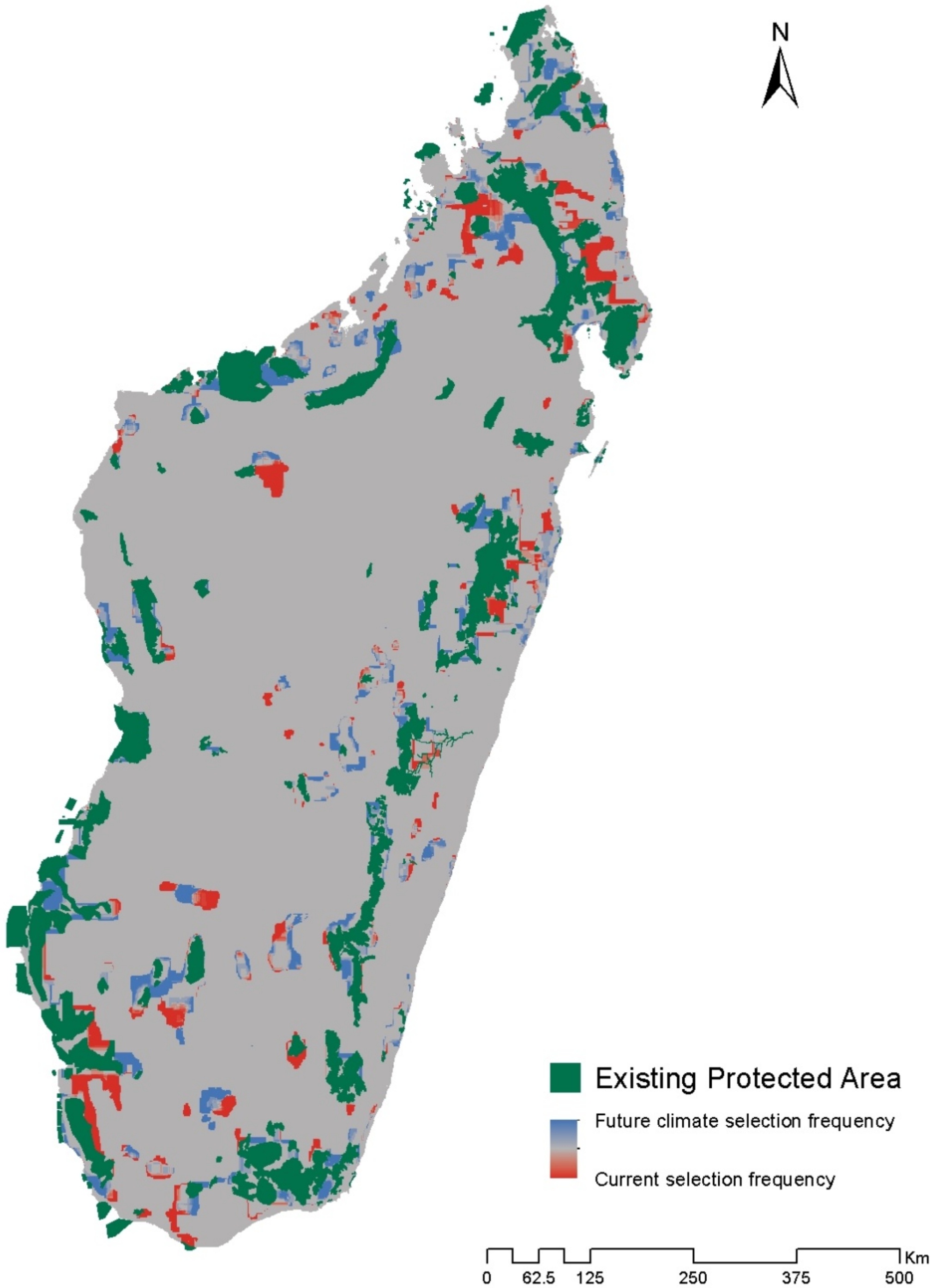

Fig. 7: Selection frequency of scenario C5 (increase in blue selection frequency) versus scenario C2 (increase in red selection frequency) from locked option (existing PA is already part of both scenarios. Red (or gradient red) color denotes a selection frequency based on current agriculture suitability as cost. Red areas were not selected by future agriculture suitability as cost (in Blue).

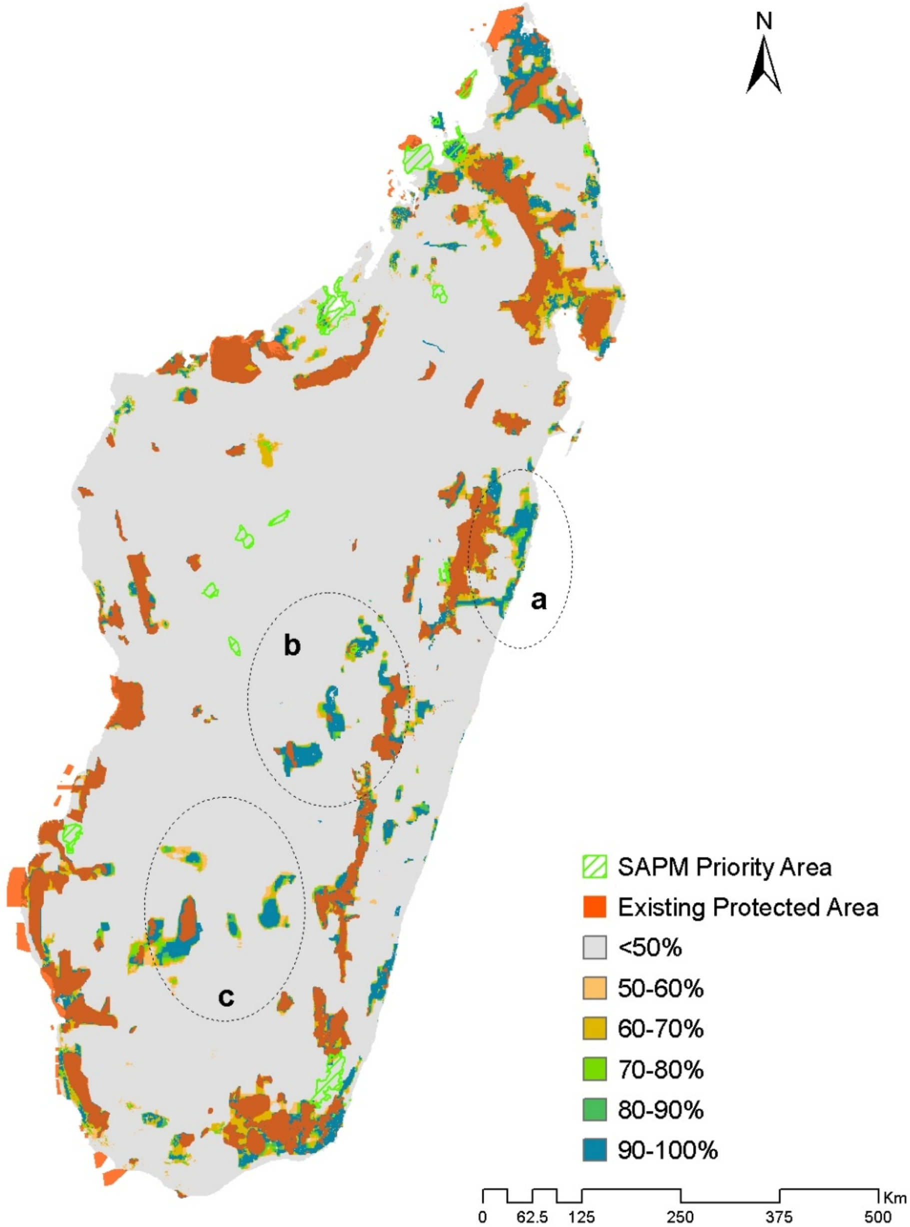

Fig. 8: Selection frequency for sum of C1, C2, and C3 scenarios. The map shows locked scenario with costs. Priority areas proposed by current government are in green hatched, and regions a, b, and c are identified as possible regions for expansion, based on frequency of selection of regions that lie outside of currently protected areas. Dark orange color illustrates the protected area that is forced to be part of the solution. Color ramp indicates the frequency of selection

Supplemental material

Taxonomic group	full species name	Target size in km2
Plant	Adansonia suarezensis	0.834877453
Plant	Alluaudia ascendens	662.4622588
Plant	Alluaudiopsis marnieriana	76.26228866
Bird	Amaurornis olivieri	1383.34343
Plant	Amyrea sambiranensis	880.2221047
Bird	Anas melleri	1373.44343
Amphibians	Anodonthyla rouxae	48
Plant	Argyreia vahibora	367.2371012
Fish	Arius festinus	55
Fish	Arius sp. Sofia	55
Fish	Arius uncinatus	94
Plant	Asteropeia matrambody	1378.152752
Bird	Aythya innotata	687.2159501
Fish	Batrachus uranoscopus	12
Plant	Baudouinia louvelii	452.3323745
Plant	Bauhinia xerophyta	140.101887
Fish	Bedotia sp. Ankavia-Ankavanana	10
Fish	Bedotia sp. Bemarivo	15
Fish	Bedotia sp. Betampona	47
Fish	Bedotia geayi	65
Fish	Bedotia sp. Lazana	167
Fish	Bedotia sp. Mahanara	24
Fish	Bedotia sp. Manombo	48
Fish	Bedotia sp. Namorona	22
Fish	Bedotia sp. Nosivolo	8
Fish	Bedotia sp. Sambava	2.313951778
Fish	Bedotia tricolor	22
Fish	Bedotia sp. Vevembe	15
Plant	Beguea glabrifolia	1557.241618
Plant	Beilschmiedia madagascariensis	2286.943455
Plant	Bonamia boivinii	303.5372154
Amphibians	Boophis andreonei	12
Amphibians	Boophis blommersae	400.721963
Amphibians	Boophis jaegeri	62
Amphibians	Boophis williamsi	34
Plant	Breonia louvelii	39.67418835
Plant	Breonia lowryi	608.7371727
Plant	Brexia alaticarpa	1397.255888

Plant	Brexia australis	13.98028694
Plant	Brexia marioniae	914.0723874
Reptiles	Brookesia perarmata	257.632593
Reptiles	Brookesia vadoni	1683.64343
Plant	Buxus itremoensis	172.9998754
Plant	Ophiocolea delphinensis	5327.04343
Plant	Cadia pedicellata	1091.476375
Plant	Calantica grandiflora	847.1075505
Reptiles	Calumma capuroni	61
Plant	Campnosperma parvifolium	139.1211713
Plant	Capurodendron microphyllum	8.542418586
Plant	Capurodendron suarezense	86.62826723
Plant	Capurodendron tampinense	453.4667542
Plant	Chadsia racemosa	67.40490973
Bird	Charadrius thoracicus	1293.54343
Plant	Chouxia mollis	77.98754366
Bird	Circus macrosceles	3548.74343
Plant	Coffea ankaranensis	1206.540343
Plant	Crotalaria ankaratrana	406.9015612
Plant	Crotalaria craspedocarpa	2580.848309
Plant	Crotalaria emirnensis	1390.093074
Plant	Crotalaria manongarivensis	693.077517
Plant	Crotalaria poissonii	687.5207458
Plant	Cynoglossum monophlebium	1537.577031
Plant	Dalbergia abrahamii	221.4267152
Plant	Dalbergia glaberrima	25.82124502
Plant	Dalbergia glaucocarpa	403.5921193
Plant	Dalbergia hildebrandtii	800.3670916
Plant	Dalbergia suaresensis	1011.667775
Plant	Dalbergia tsaratananensis	846.3280147
Plant	Dalbergia xerophila	321.4772621
Plant	Dialyceras coriaceum	691.9169329
Plant	Dialyceras discolor	102.5019952
Plant	Dialyceras parvifolium	314.9377757
Plant	Dichrostachys dumetaria	466.4497551
Plant	Dichrostachys venosa	1217.276311
Plant	Dicoma grandidieri	1249.103657
Plant	Diegodendron humbertii	1019.087223
Plant	Ehretia australis	754.5985033
Plant	Ehretia decaryi	246.9381142
Plant	Eligmocarpus cynometroides	214.5193634
mammals	Eliurus petteri	492.9335372

Plant	Erblichia berneriana	560.4552588
Reptiles	Erymnochelis madagascarensis	1381.64343
Plant	Erythrina ankaranensis	34.15321053
mammals	Eulemur albocollaris	316.3759791
mammals	Eulemur coronatus	755.6085003
mammals	Eulemur mongoz	998.8343742
mammals	Eulemur sanfordi	656.7746578
Plant	Euphorbia ankaranae	110.8058183
Plant	Euphorbia didiereoides	42.83411549
Plant	Euphorbia elliotii	167.6621767
Plant	Euphorbia enterophora	1843.397614
Plant	Euphorbia francoisii	15.53276111
Plant	Euphorbia horombensis	651.189334
Plant	Euphorbia mandravioky	172.4920942
Plant	Euphorbia milii	514.3714392
Plant	Euphorbia perrieri	606.4320394
Plant	Euphorbia perrieri	669.8533603
Plant	Euphorbia primulifolia	522.1410714
Plant	Euphorbia quartziticola	128.9214689
Plant	Euphorbia salota	1536.599957
Plant	Exacum fruticosum	14.08375267
Plant	Exacum microcarpum	481.3250985
Plant	Exacum millotii	974.178794
Plant	Fatoua madagascariensis	977.4801729
Plant	Faucherea urschii	849.2112733
Reptiles	Furcifer angeli	321.393376
Reptiles	Furcifer belalandaensis	20
Reptiles	Furcifer bifidus	1142.750366
Reptiles	Furcifer minor	165
Reptiles	Furcifer petteri	831.9361695
mammals	Galidictis grandidieri	491.9621221
Reptiles	Geochelone yniphora	240.0329903
Plant	Gladiolus decaryi	938.4319158
Plant	Gladiolus perrieri	1550.402555
Fish	Glossobius ankaranensis	237.8840429
Plant	Gnidia danguyana	1824.585899
Plant	Gonioma malagasy	1052.861282
mammals	Hapalemur alaotrensis	209.9140598
mammals	Hapalemur aureus	856.595181
Plant	Hilsenbergia croatii	881.9973363
Plant	Humbertiella quararibeoides	32.21422393
mammals	Hypogeomys antimena	181

Plant	Indigofera blaiseae	191.9202607
Plant	Indigofera bosseri	1304.166655
Plant	Indigofera thymoides	496.0294384
Plant	Ipomoea pseudomarginata	850.8964203
Reptiles	Langaha pseudoalluaudi	33
Plant	Lemuropisum edule	205.8566452
Plant	Lepidotrichilia ambrensis	652.578487
mammals	Lepilemur dorsalis	1133.007399
mammals	Lepilemur edwardsi	1181.8312
mammals	Lepilemur septentrionalis	69
Plant	Leptodesmia bojeriana	917.6647673
Plant	Leptolaena delphinensis	181.9265565
Plant	Leptolaena itremoensis	61.66006883
Reptiles	Liophidium apperti	494.3881567
Plant	Ludia dracaenoides	534.7667104
Reptiles	Lycodryas inopinae	36
Reptiles	Lycodryas tulearensis	1252.74343
Plant	Faguetia falcata	6565.84343
mammals	Macrotarsomys ingens	503.5317914
Plant	Hilsenbergia leslieae	4480.44343
Amphibians	Madecassophryne truebae	683.1610982
Plant	Jatropha mahafalensis	4504.44343
Plant	Wielandia laureola	3294.34343
Plant	Crotalaria ibityensis	4310.84343
Plant	Crotalaria poissonii	3053.44343
Plant	Pyranthus lucens	11935.04343
Amphibians	Mantella bernhardi	15
Amphibians	Mantella cowanii	5
Amphibians	Mantella crocea	837.4741595
Amphibians	Mantella expectata	320.1427309
Amphibians	Mantidactylus guibei	50
Amphibians	Mantella haraldmeieri	412.2607891
Amphibians	Mantidactylus klemmeri	343.4985167
Amphibians	Mantidactylus madecassus	138
Amphibians	Mantidactylus microtis	115
Amphibians	Mantella milotympanum	47
Amphibians	Mantidactylus pauliani	96
Amphibians	Mantella pulchra	711.0446006
Amphibians	Mantella viridis	370.1180094
Amphibians	Mantidactylus webbi	617.6379593
Plant	Martellidendron androcephala	767.0773529
Plant	Martellidendron karaka	128.5295535

Reptiles	Matoatoa spannringi	7
Plant	Melanophylla modestei	9.622166909
Fish	Mesopristes elongatus	47
mammals	Microcebus berthae	323.2647588
mammals	Microgale jenkinsae	40
mammals	Microgale nasoloi	108
mammals	Microcebus tavaratra	217.4154012
Plant	Mitreola turgida	893.8142773
Bird	Monticola erythronotus	237.8840429
Plant	Mucuna manongarivensis	272.2826058
Plant	Mundulea anceps	791.2004101
Plant	Mundulea menabeensis	677.2458106
Plant	Neoharmsia baronii	264.4329453
mammals	Neoromicia malagasyensis	331.9263287
Plant	Nesogordonia fertilis	456.1308621
Plant	Nesogordonia humbertii	351.3316132
Plant	Nesogordonia pachyneura	429.9086306
Plant	Oliganthes sublanata	227.7656646
Plant	Operculicarya hirsutissima	379.4016004
Plant	Operculicarya pachypus	57.33528474
Reptiles	Oplurus fierinensis	125
Plant	Ormocarpum bernierianum	1225.235218
Plant	Ormocarpopsis mandrarensis	2821.866472
Plant	Ornichia trinervis	489.0415483
Fish	Oxylapia polli	8
Plant	Dypsis forficifolia	6475.24343
Fish	Pachypanchax sp. Analalava	448.3519562
Plant	Pandanus biceps	21.65794218
Plant	Pandanus comatus	1398.845607
Plant	Pandanus connatus	19.18525929
Plant	Pandanus coriaceus	1227.863394
Plant	Pandanus kimlangii	972.0693034
Plant	Pandanus mammillaris	101.9897835
Plant	Pandanus microcephalus	382.9292611
Plant	Pandanus neoleptopodus	752.8335583
Plant	Pandanus pluriaculeatus	794.9724923
Plant	Pandanus pristis	113.3003415
Plant	Pandanus pseudobathiei	435.8630047
Plant	Pandanus pseudocollinus	770.8354755
Plant	Pandanus rollotii	1374.561787
Plant	Pandanus sambiranensis	249.9798422
Plant	Pandanus saxatilis	270.9282448

Plant	Pandanus tsaratananensis	355.9397402
Fish	Pantanodon sp. Manombo	48
Fish	Paratilapia sp. Fiamanga	664.7982796
Reptiles	Pararhadinaea melanogaster	73
Fish	Paratilapia typus	15
Fish	Paretroplus sp. Dridri mena	62
Fish	Paretroplus maromandia	33
Fish	Paretroplus nourissati	55
Fish	Paretroplus sp. Sofia	55
Fish	Paretroplus sp. Ventitry	489.5277156
Plant	Pentachlaena latifolia	285.7614592
Plant	Perrierodendron quartzitorum	80.08250353
Plant	Pervillaea decaryi	891.373649
Plant	Pervillaea venenata	1549.624921
Plant	Unknown	447.8992567
Reptiles	Phelsuma antanosy	384.4591413
Reptiles	Phelsuma klemmeri	151
Reptiles	Phelsuma pronki	312.5867205
Reptiles	Phelsuma serraticauda	19
Reptiles	Phelsuma standingi	920.9448746
Plant	Phylloxylon spinosa	228.6785866
Amphibians	Platypelis mavomavo	250.6573189
Amphibians	Plethodontohyla brevipes	247.8434364
Amphibians	Plethodontohyla guentherpetersi	168
Amphibians	Plethodontohyla tuberata	708.557192
Plant	Polyscias abrahamiana	683.0236519
Plant	Polyscias andapensis	19.84734348
Plant	Polyscias heineana	107.546101
Plant	Polyscias lancifolia	327.1427557
Plant	Polyscias randrianasoloi	318.6878812
Plant	Polyscias terminalia	16.56669494
mammals	Prolemur simus	424.1446098
mammals	Propithecus coquereli	874.5565139
mammals	Propithecus coronatus	924.4275435
mammals	Propithecus deckenii	1371.34343
mammals	Propithecus perrieri	215.1760469
mammals	Propithecus tattersalli	288.0402255
Reptiles	Pseudoxyrhopus kely	441.0733784
Fish	Ptychochromis sp. Garaka	81
Fish	Ptychochromis sp. Green Garaka	62
Fish	Ptychochromis inornatus	135
Fish	Ptychochromis sp. Joba mena	55

Fish	Ptychochromoides katria	8
Plant	Pyranthus ambatoana	629.6075674
Plant	Pyranthus monantha	1105.922022
Plant	Pyranthus pauciflora	1408.008812
Reptiles	Pyxis planucauda	616.0093386
Fish	Rheocles derhami	77
Fish	Rheocles wrightae	216.6699876
Plant	Rhodolaena acutifolia	253.7364489
Plant	Rhodolaena altivola	1369.326649
Amphibians	Rhombophryne testudo	131
Plant	Rhopalocarpus binervius	741.4715512
Plant	Rhopalocarpus excelsus	1100.452304
Plant	Rhopalocarpus longipetiolatus	585.9243925
Plant	Rhopalocarpus suarezensis	54.25019853
Plant	Rhopalocarpus thouarsianus	1320.971472
Plant	Rhopalocarpus triplinervius	831.3451516
Plant	Rhopalocarpus undulatus	782.092209
Plant	Rhynchosia baukea	1647.990135
Plant	Sarcolaena grandiflora	776.111792
Bird	Sarothrura watersi	10
Amphibians	Scaphiophryne boribory	50
Amphibians	Scaphiophryne gottlebei	229.9332248
Plant	Schizolaena gereaui	2068.507934
Plant	Schizolaena microphylla	2996.14284
Plant	Schizolaena parviflora	1455.198425
Plant	Schizolaena pectinata	1942.208011
Plant	Schizolaena rosea	893.1767715
Plant	Schizolaena turkii	353.4390096
Plant	Schizolaena viscosa	687.6448852
Plant	Secamone humbertii	47.40628735
Plant	Secamone toxocarpoides	422.0530754
Plant	Securinega antsingyensis	1915.655517
Plant	Solanum humblotii	1423.970826
Plant	Solanum myrsinoides	501.0049227
Plant	Stephanodaphne cremostachya	47.42292771
Plant	Stephanodaphne cuspidata	180.848226
Plant	Stephanodaphne schatzii	129.9295971
Amphibians	Stumpffia helenae	8
Amphibians	Stumpffia pygmaea	96
Plant	Tabernaemontana eusepala	980.3543622
Plant	Tabernaemontana sambiranensis	270.4323067
Plant	Tachiadenus boivinii	833.9272045

Plant	Tachiadenus longiflorus	393.8316784
Plant	Tachiadenus tubiflorus	919.9029499
Plant	Takhtajania perrieri	848.9465805
Plant	Tannodia grandiflora	414.5590097
Plant	Tephrosia betsileensis	338.4631666
Plant	Tephrosia bibracteolata	1264.543179
Plant	Tephrosia isaloensis	78.19564514
Plant	Tephrosia parvifolia	1474.71919
Plant	Tephrosia phylloxylon	1217.953375
Plant	Tephrosia subaphylla	257.0039492
Plant	Tephrosia viguieri	800.9196804
Plant	Tephrosia villosa	3355.922743
Fish	Teramulus waterloti	94
Plant	Thespesia gummiflua	74.28509912
Plant	Tisonia crenata	1213.85095
Fish	Typhleotris madagascariensis	412.8054393
Plant	Uncarina leptocarpa	1725.242449
Plant	Uncarina perrieri	1016.470554
Plant	Uncarina stellulifera	2067.793016
Reptiles	Uroplatus malahelo	132
Plant	Vaughania humbertiana	10.99826264
Plant	Vaughania longidentata	175.733418
KBA	Vegetation	1413.84343
KBA	Vegetation	239.317585
KBA	Vegetation	879.4308617
KBA	Vegetation	1244.84343
KBA	Vegetation	740.1851564
KBA	Vegetation	959.1566212
KBA	Vegetation	70
Plant	Voatamalo eugenioides	501.6393649
Plant	Weinmannia aggregata	367.8549444
Plant	Xerophyta andringitrensis	2057.350046
Plant	Xerophyta aymoninii	1190.551103
Plant	Xerophyta croatii	1439.596506
Plant	Xerophyta eglandulosa	57.66890487
Plant	Xerophyta labatii	2118.232134
Plant	Xerophyta leandrii	1747.43688
Plant	Xerophyta lewisiae	1096.815696
Plant	Xerophyta pinifolia	1860.613478
Plant	Xerophyta schatzii	1436.382888
Plant	Xerophyta sessiliflora	2501.939592
Plant	Xerophyta tulearensis	1189.914119

Reptiles	Zonosaurus anelanelany	66
Reptiles	Zonosaurus boettgeri	714.9346756

CHAPTER IV

Understanding forest clearing and conservation policy: the case of the Makira Protected Area

Summary

This research explores the current status of the Makira Protected Area, and analyzes the relationship between land uses to a community management strategy. I first examined how the forest management contracts were set up and administered, and then assessed the efficacy of these contracts with respect to institutional effectiveness (Ostrom 1990) and reduction of deforestation, the key driver of biodiversity endangerment in Madagascar (Kremen et al. 2008; Harper et al. 2008). The approach taken in this research is a combination of semi-structured interviews, group interviews, participant observations, and land use mapping. From 2009 to 2011, I conducted a detailed land use survey of 8 sites in the eastern side of the Makira Protected Area, a large rain forest area in northeastern Madagascar. A total of 135 households were visited and a full land use survey was conducted for each household. Households were revisited a year after for a follow-up to identify if households followed on their forest clearing plan. In addition, 5 other communities were observed during the process of setting up the community management arrangement. In this study, I first present a qualitative narrative of the processes of establishing management transfer. Second, I evaluate the forest management contracts in Makira Protected Area relative to the 8 design principles of Ostrom (1990) for management of common property resources. Third, I present data from household surveys showing the prevalence of deforestation in forest management contract areas.

Introduction

In the past two decades community based natural resource management (CBNRM) has emerged as a widely used conservation strategy globally (Dressler et al. 2010). The shift to CBNRM from more top-down forms of conservation emerged from observations of top-down management failures, where collective resistance to protected areas undermined conservation objectives (West & Brechin 1991). It also was supported as a more ethical (Kellert et al. 2000) way to relieve overburdened state agencies tasked with policing and managing an increasing number of protected areas (Neumann 1997).

Deforestation has been a key focus of conservation efforts in Madagascar since colonization by the French in 1895. It is well-documented that rural populations in Madagascar clear forests and transform land into agricultural fields (Gade 1996; Laney 2004; McConnell & Sweeney 2005; Vågen 2006; Harper et al. 2008). Madagascar now has little more than 15% forest cover remaining (Harper et al. 2008), with subsistence agriculture and relatively small farms visibly dominating the landscape. Various studies have focused on particular issues related to deforestation in different localities around Madagascar: for example, Kull, (1998) addressed the problem of fires in Leimavo, in central highland Madagascar; Laney (2002) conducted a case study on agricultural intensification in Andapa; Mcconnell, (2002); Vågen, (2006) used remote sensing to better understand deforestation rates in Vohibazaha and Ambositra in Madagascar central high plateau region, and Scales (2012)analyzed conservation policy socio-cultural changes and forest clearance in Menabe region. These various studies agree that agricultural land use practices interfere with current conservation policy and there is a strong need to devise new solutions to remedy the conflict between agriculture and biodiversity conservation.

In Madagascar, similar to the conservation paradigm trajectory occurring elsewhere in the world, the first protected areas in Madagascar established during the colonial period were strict nature reserves and, once established, local people were no longer permitted access to any of the resources within these reserves. A conference on conservation for sustainable development was organized in Madagascar in 1985 which led to the publication of the first of three National Environmental Action Plan (NEAP) for Madagascar, with the help of foreign donor and lending institutions (Peters 1998b; Gezon 2007; Kull et al. 2007). The first NEAP Phase (1991 – 1997) was focused on establishing new institutions such as the peristatal, Protected Area Management agency ANGAP (Association National de la Gestion des Aires Protégées, later re-titled as Madagascar National Parks - MNP), and promoted policies resulting chiefly in top-down forms of management, such as Integrated Conservation and Development Programs (ICDP) (Peters 1999; Kaufmann 2006) at Masoala (Kremen et al. 1999), Ranomafana (Peters 1998b) and Marojejy National Parks. NEAP 1 ended with heavy criticism concerning the lack of attention to local communities. Locals were seen as continuing to constitute a direct threat to natural resources, despite so-called benefits that the ICDP projects aimed to deliver to local communities, instead of participants in the management process (Gezon 1997). Still, one tangible benefit were the laws enacted to bring 50% of the revenue from park entrance fee to fund local communities' project (Peters 1998a).

Similar to a phenomenon observed throughout the world, especially in sub-Saharan Africa, Madagascar moved from a largely top-down to a decentralized management paradigm during Phase 2 (1997 - 2003) of NEAP (Gezon 2007). This phase focused particularly on the role of local communities in natural resources management. While NEAP 1 was seen as crafted by the donors and international institutions, NEAP 2 was allegedly the result of more concerted effort from local actors and nationals. GELOSE (*Gestion Locale Securisée*) legislation was enacted to delegate the management responsibility and legal tenure over community protected areas to local communities (commonly called COBA, *Communautés locale de Base*). Massive restructuring took place and resulted in the creation of new government agencies including the office for the implementation of GELOSE.

While the GELOSE was put into law in 1998, the first legal precedence for community participation in conservation (Bertrand 1999), it was generally seen as cumbersome and presented a significant obstacle for communities to engage, due, for one to the difficulties with completing all of the necessary paperwork, given low literacy rates within the rural population. A simplified version, GCF (*Gestion contractualisée forestière*) decree was established in 2001, called the Forest Management Contract law. GCF was created to provide a more flexible and simplified route for local communities to engage in forest management. GCF is based on the forest management principle whereby a villages' forested "territory" is divided into zones of different management, such as sustainable timber harvest, restoration, and strict protection (Equipe-MIRAY 2002). Both GELOSE and GCF were oriented to have communities manage any of the various resources they possessed, including native silkworms that can be used to produce silk, plants that produce essential oils, ginger, and, most frequently, timber. In some instances, these projects were able to generate enough cash to fund community development projects (Hockley & Andriamarovololona 2007). Many resources within forests could also be used by villagers for local consumption, for house, boat and furniture construction materials, foods, firewood and medicines (Kremen et al. 1998; Golden 2009).

In both GELOSE and GCF legislation, local communities can be co-managers or full managers of Protected Areas that were formerly state-owned. In fact, all forested lands in Madagascar are owned by the state (constituting the *Forêt Domaniale*), whether they are in a PA or not, unless they are owned by a private land-owner with a legal tenure document. However, few of Madagascar's population living near forested lands and utilizing these regions, have such legal tenure documents, operating instead under "customary land tenure". Both GELOSE and GCF therefore transfer management over forested lands from the state to local communities. However, in "simplifying" the process through which a community can gain control over forested lands, the GCF process dropped a key piece of the legislation: the right of the community to full tenure over the protected area.

NEAP Phase 3 started in the second half of 2003 (Fig. 3). The program was not officially funded until July of 2004 when cooperation between the Madagascar government and the International Development Association / Global Environmental Facility (GEF) was signed. Three major policy changes occurred at the early stage of NEAP 3 which concurred with the world park congress meeting in Durban, South Africa. The first change was the call from international conservation NGOs acting in Madagascar to adopt the IUCN six categories system for protected areas (PAs) (Borrini-feyerabend & Dudley 2005), which permit designating PAs along a spectrum from complete wilderness to managed landscapes. The second policy related to an announcement from the President of Madagascar to triple the size of PAs, which was 1.8 million hectares at that time. This policy is famously called the Durban Vision. The third change was to fund this expansion of protected areas in the third phase of NEAP partially through payment for ecosystem services, again indicative of a global trend towards using the logic of the market to conserve biodiversity(Ferraro & Kiss 2002).

In this paper, I document the application of the new GCF law in a large, biodiversity-rich region in Northeastern Madagascar, the Makira Protected Area, which includes a Community Management Zone in which the GCF is applied. Using mixed sociological methods, including semi-structured interviews, group interviews, participant observations and land use mapping, I first examined how the forest management contracts were set up and administered, and then assessed the efficacy of these contracts with respect to institutional effectiveness (Ostrom 1990) and reduction of deforestation, the key driver of biodiversity endangerment in Madagascar (Kremen et al. 2008; Harper et al. 2008)

Materials and Methods

The Makira Protected Area and surrounding Community Forest Management Zone

Makira Protected Area (MPA) is located in the northeast of Madagascar (Fig. 1) and is currently the largest terrestrial protected area (PA) of the country. MPA had been under temporary protected area status since 2005, but a government decree in August 2012 finally designated it as a full PA. The park exemplifies national values that emerged both in the 2nd and 3rd phases of the NEAP.

The park design includes a three-part zoning system as written in the PA code (Bertrand 1999; Madagasikara 2005): the Zone of Strict Protection, the Multiple-Use Zone and the Community Forest Management Zone. The Zones of Strict Protection plus Multiple Use total 372,470 hectare, while the Community Management Zone is approximately 280,000 hectare, but continues to increase as more communities participate in the management transfer under GCF. The management of MPA is delegated to the Wildlife Conservation Society (WCS) , an international non-government organization based in New York, and the park's funding comes primarily from a payments for ecosystem services scheme, the Reducing Emissions from Deforestation and Degradation Plus (REDD+) project (Holmes et al. 2008; Bidaud 2012), which finances biodiversity conservation projects through the sale of carbon credits for avoided deforestation (Gardner et al. 2011; Bidaud 2012).

With an average annual rainfall of 3500mm, MPA contains lowland to mid-altitude humid forest. The highest mountain reaches 1300m. Although few biological inventories have been conducted inside MPA (Rakotomalala et al. 2007; Rasolofoson et al. 2007; Rakotoarinivo et al. 2009), the site is expected to contain up to 50% of Madagascar's unique biodiversity, including the highest diversity of lemurs in all of Madagascar's PA (Holmes et al. 2008) (Table 1).

The Community Forest Management Zone, created under GCF, started in 2004 with 10 communities and reached up to 53 communities as of December 2011; in each case, land and natural resource management rights are transferred from state control to local communities under a GCF contract. Most of these lands have already been affected by deforestation (Fig. 2). All activities related to the Community Forest Management Zone have been initiated and implemented by WCS. The MPA project alongside the local community and the Forestry Department has agreed to focus on sustainable management to meet the long term needs of the local populations for natural resources while maintaining forest cover. The goals are to reduce the human pressures in these so called green belt zones (community zones).

With regard to the social and economic context, MPA's Community Management Zone is home to more than 150,000 people in 82 distinct communities. There are two primary ethnic groups: Tsimihety, more dominant in the Northwest (53.9%) and Betsimisaraka (42.7%) mostly in the Southeast. The rest of the population is represented by relatively recent immigrants from different locations of Madagascar. Cash crops such as cloves and vanilla are the main source of cash revenue for 65% of the households. Although mostly for local consumption, rice produced in this area is also sold by some famers with large fields. Forest clearing and economic activities are closely correlated around Makira. Forest is cleared primarily for slash and burn agriculture (tavy) to grow rain-fed rice.

Framework of institutional analysis

This study focuses on the effectiveness of the forest management transfer (GCF) process through a local scale analysis, examining (1) the institutional effectiveness of the GCF, and (2) the effectiveness of this conservation policy for reducing deforestation.

I chose to use the 8 design principles of Ostrom (1990) to evaluate the transfer of forest management around MPA. These principles are posited to characterize a robust institution and they are well supported by empirical evidence (Cox et al. 2010). Ostrom (1990:90) listed the following design principles:

1. Clearly defined boundaries of the common property resource (CPR) or area to be managed
2. Congruence between appropriation and provision rules and local conditions: Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions.
3. Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying the operational rules.
4. Monitoring: Monitors, who actively audit Common Pool Resources (CPR) conditions and appropriator (the resource user) behavior, are accountable to the appropriator or are the appropriators.
5. Graduated sanctions: Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense)

by other appropriators, officials accountable to these appropriators, or both.
6. Conflict-resolution mechanisms: Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
7. Minimal recognition of rights to organize: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.
8. Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

I evaluate the GCFs implemented within the Community Management Zone of the MPA against these principles in order to identify the possible failure of GCF in the Community Management Zone.

Field research methodology

The field research methodology was a combination of participant observation, group interviews, questionnaires, and physical mapping of land by using global positioning system (GPS) units. The methodological guideline of Converse, (1986) and Babbie, (2001) were utilized for all surveys. A land use survey was conducted in 8 villages for a total of 135 households, between 2009 and 2011 (Table 2). This study is a part of my larger research program on deforestation and household decision-making in MPA. Many other variables such as household size, productivity or rain fed or irrigated rice agriculture, other land holdings, etc., were recorded but will not be part of this analysis, which is instead focused solely on the effectiveness of the GCF as an institution for forest management.

Between March and April 2009, I attended meetings in villages that were not yet participants in the Community Forest Zone to observe the first stages of the GCF process. During this time, I visited 5 villages in the western side of the MPA, documented the activities related to GCF, and had an open-ended interview with the team implementing the management of community forests. I assisted in the following activities, depending on the advancement of the process in any specific village: village limit mapping, forest resource inventory, management plan, and election of the forest management committee (COGE), discussion of regulations and fines, and final signing of the contract with the regional authority.

Between January 2009 and August 2010, I observed 8 GCF communities located on the eastern side of the MPA, 4 of which signed a GCF contract in 2004 and 4 that signed it in 2006. I set up a group interview for each of the villages, and asked about the boundary of the village, the different people in charge of monitoring. For these same villages, I also mapped individual household land holdings and conducted household surveys with the head of household, and recorded the following variables:

- The total forest area cleared in 2009
- The area of forest considered owned by them in 2009

- YES/NO Response from household on their plans to clear forest in the next agricultural season 2010 or not

Villagers practice a system of customary land tenure. They consider lands to be “owned” by them, including forested lands that are part of the “Forêts Domaniales” that is legally owned by the state, when forested land is cleared and marked by a perennial culture. At the community level, forests are divided according to social organization, customs and practices in the villages. They are considered as land-reserves. I conducted a repeat survey to track if the household actually carried out their plan to clear forest. Thus I recorded another YES/NO Response from household on whether clearing forest occurred in 2010. Only one household out of the 135 interviewed did not participate in the follow-up survey, due to a death in the household. Before the final data analysis, 10 households were removed from the dataset because of large spatial errors in mapping. These data falls outside of their household attribute range.

Results

Narratives and data analyses are presented in three steps. First I will present a qualitative narrative of the processes of establishing management transfer. Second, I evaluate the GCF in Makira Protected Area relative to the 8 design principles of Ostrom (1990) for management of common property resources. Third, I present data from household surveys showing the prevalence of deforestation in GCFs.

a- Process of setting up GCF

The MPA has engaged in a vast implementation of GCF in the peripheral zone of the PA. The details of this process are presented in Table 3. The stated goal of GCF in MPA is to manage forest resources sustainably in order to maintain the ecological balance in the region (Holmes et al. 2008).

In theory, there is a step-by-step process with which the GCF is established. For example the first step in implementing the GCF should consist of making sure that everyone is aware of the project, particularly the regional and local authorities. The idea behind this is to ensure the political backing of all activities. The early steps are supposed to be spent on trying to provide exact information about the GCF to the local community. The next step is to set up the community management structure. For instance having the first meeting of the GA, or the decision making body composed of everyone who is present at the first meeting, and electing the community management committee (COGE)(Fig. 4). In theory the promoting organization collects and compiles information about the basic socio-economic context of the community and their land use via the rapid rural appraisal methodology (RRA). Development of a land use map requires the full participation of the community as it would potentially be a source of conflict with the neighboring communities in the future if not done properly. Natural landmarks and limits are recognized and then mapped with a GPS unit.

While the different steps outlined above appear to require response and participation from the community, in practice, setting up the management transfer in the MPA was implemented as a "one solution fits all method". All of the observed communities were given the same rules (known as *dina*), the same management plan and the same restrictions on use of forest products. For instance clearing new land, practicing bush fire, and hunting protected animals are all considered criminal offenses. These rules are applied to non-members of the community as well. In fact, residency in the village does not guarantee membership in the GCF. Villagers must pay a fee per annum. Non-members of the community also pay a higher fee to collect resources from the community's managed forests.

GCF contract is valid for three years and renewable for a period of 10 years after a successful evaluation of management. The transfer of management is a contract between the Forest Administration and the COBA. The President of COBA along with the representative of the Forest Service signs the document. This finished document stipulates the rights and obligations of all parties concerned and must be discussed and approved by the General Assembly (GA) which is the periodical general meeting of GCF. The specifications document is developed by the Forest Administration to conform to the current laws. A management plan developed with the promoting organization (in this case, WCS) is attached to the management contract as well as a list of agreed internal rules.

b- Eight design principles

Principle 1: well defined boundary

Identifying the community forest physical boundary is done through two processes: first: a debate between members of the community over the known traditional boundary, with identification of all landmarks, and second, mapping community forests with precise tools such as a global positioning system. This is usually done in order to identify potentiality and resources, as well as location of the users. Although traditional boundary knowledge is oral not written in all instances, the boundaries of community forests were very consistent and well known by community members throughout Makira forest (Fig. 7). I did not observe any cases of overlap between neighboring communities. I noticed two communities that have members owning land inside the current PA: Sahajinja Manonga and Anjiahely. This design principle therefore appears to be respected.

Principle 2: Congruence between appropriation and provision rules and local conditions

One of the stated objectives of GCF is to stop deforestation and move toward more sustainable uses but reconciling the two concepts is a difficult task for the local community. All GCF contract around Makira reflect the conservation approach to resources use by imposing a fee for forest products extraction, doubling the fee for non-members living in the community, and completely banning destructive practices such as fires or vegetation clearance. In fact a permit is necessary for anyone clearing their own customary recognized agricultural land. There is no room for negotiation as the promoting organization (WCS) are calling for more restriction on forested product use by the text on forest law (Art.12, Law 97-017). This is seen as the general failure of GCF as restriction is imposed in some activities such as fire or vegetation clearance for any purposes.

Principle 3: Collective-choice arrangements where member of COBA affected by the rule can modify the operating rules

There is a venue for COBA to change the rules but it is not far-reaching. In fact, during their General Assembly, which can be held as many as three times a year, COBA members can modify the amount of fees for resource access. In one case, members have voted in favor of complete removal of resource extraction fees (e.g. the community in Andranovolo). However, only the Forestry Administration is in the legal position to write the "specification documents" (*cahier de charge*) that set the conditions of. This "specification document" is the tool for making the management plan and creates sets of rules for the community. The inability of the local community to influence the specification document is another weak point of GCF.

Principle 4: Monitoring

Monitoring of resource uses is supposed to be ensured by the appointed chiefs of the valley. Chiefs of the valley are the representatives of the family occupying a portion of the community's land. Each chief is supposed to report to the management committee (*Comité de Gestion*, COGE) all infractions. The issues here are that, one valley is usually occupied by a large family and the Chief of this valley is reluctant to report any resource extraction by their own family. The president of the COBA in Anjiahely has mentioned this problem as his main concern. An external monitor is sometimes called, that is WCS agents, but this usually ends by creating conflicts within the community. For example, following external monitoring of tree cutting infraction, a member of COBA was arrested in Anjiahely in August 2010, which later led to the resignation of the president of the COBA because of the community's pressure. In principle, this design principle is being followed, but it is not fully effective.

Principle 5: Graduated sanctions

This principle is supposed to maintain the community's cohesion however too much community cohesion also works toward zero sanction. Resolution of dispute is clearly in graduated manners. Infractions are treated at the local level then send to the Communal authority if not resolved, or to the courts if not resolved at the Communal level. However, sanctions can be too severe or too relaxed, disproportionate to the local economy or the capacity to pay fine. For instance, the daily wage is about $1 a day, and the cutting one tree can cost as much as $5 to the offender.

Principle 6: Conflict-resolution mechanisms

Under GCF, internal conflicts are treated at the local level by paying a fine per resource extracted. Such conflicts are rarely officially reported. To date, there has never been a recorded conflict with any external group wishing to extract resources in any of the observed GCF. It is stated under the contract that one of GCF's advantage is to be able to stop any external group in extracting their resources. For instance, in southern Makira (Rantabe), quartz miners are immigrating into community's territory.

Principle 7: Minimum recognition of rights

GCF is a management transfer right not a property transfer right, thus there is no tenure security associated with the system. The state remains the owner of the resource, and by the action of Forestry Administration, they can take back the management if there are repeated violation of the rules, as stated in the contract of management. Therefore, this design rule is not respected.

Principle 8: Nested enterprises

There are multiple layers of the legal system that regulate GCF. GCF in itself is a government decree transferring user and manager rights for natural resources to the local community. Thus, the COBA, the management authority created by the GCF is recognized at higher levels of government. The second layer is the set of rules governing resource use that is created by the community called "dina". Dina must have the approval of a regional Court, signed by a judge, to be tested for conformity to criminal law.

c- Household surveys

While 91% percent of households declared that they planned to clear new forest or secondary forest when asked in 2009, only 80% of households carried out that decision in 2010 across all communities. 74% of households continued to grow rain fed rice (i.e. using slash and burn fields) from 2009 to 2010 across all communities (Fig. 5). Anjiahely had the highest difference in percentage of planned to actual forest clearing, reduced from 93% to 33%. The average forest cleared per household per year is 0.57 hectare, but that value varies from 0.18 hectare in Anjiahely to 1.2 in Sahajinja (Fig. 6). The average forest plot size owned by a household is 0.88 hectare, (minimum at 600 m2 and maximum 6.6 hectares).

Discussion

The effectiveness of CBNRM in Madagascar

One of the goals of CBNRM is the decentralization of the decision making authority to the local community (Corson 2011). Further, in order to be supportive of conservation activities, people need to access resources, and furthermore need to be direct beneficiaries of the conservation efforts. However, we observe instead a reinforcement of the state power by having NGO representation in and around the parks and reserves in Madagascar. In fact, in evaluating the institutional effectiveness according to the 8 design rules proposed by (Ostrom 1990) for effective management of common property resources, I found that only two of the design conditions were unequivocally met. Boundaries were well understood and the GCF system created a nested enterprise. None of the other design principles, however, were applied without problems in the GCF. Thus, while in theory, CBNRM is a good solution to continuing conservation when a government is weak or overburdened, it is not guaranteed that the COBA in Makira or other parts of Madagascar will have better management of the natural resources and will eventually stop the massive deforestation.

Under both the GCF and GELOSE legislation, the Malagasy government agrees to give local communities the management decision over their land and resources after fulfilling certain requirements. Despite the legal support of CBNRM, communities are not able to fully make management decisions concerning their resources. Instead of local knowledge and interests driving the establishment of CBNRM, communities are forced into trying to enforce protectionism (Hockley & Andriamarovololona 2007) instead of sustainable resource use. The management objectives in the case of Makira were typically defined by WCS and the rule of strict forest conservation and forest restoration was imposed, even if that was not the community's priority. This phenomenon is not an isolated case from Makira, it is in fact the norm for community-based conservation projects happening all across Madagascar (Razafy & Rambeloarisoa 2007). It is clear for the case of Makira, installing GCF is way to curtail forest clearing, not transferring management authority to local communities. This practice is questioned by many actors, and is called non-voluntary participation in community conservation (Randriarimalala 2006; Raik & Decker 2007).

To reiterate, the major problems Makira faces in instituting a successful CBNRM project included : a clear lack of interest of the local community to participate in activities related to the environment, or to conservation and sustainable management of natural resources, and the fear of taking responsibilities for enforcing rules by COBA members or COGE. This is observed often in the opposition of certain groups who see their interests depressed by the GCF. It is simply difficult for COGE or the COBA members to take action against the violation of rules, due to familial and other social ties. Further, communication and access are very difficult in Makira, thus leading to fewer visits by WCS to the community. The high illiteracy rates made it difficult for local people to read and understand the details in the management transfer document and deeply engage with the contents of the agreement. Finally, the extreme poverty of some farmers forces them to engage in collecting forest products despite the rules that are set up.

Land tenure and deforestation and community

Tenure issues can contribute as precursor of forest clearance. Laney (2004) demonstrated that conservation is seen as a threat to the availability of land for future generations. In fact, given the difficulty of obtaining land tenure officially in Madagascar, the only way for people to claim ownership is *via* the traditional practice of clearing the land (Nambena 2003). Similar problems have been reported in Ranomafana National Park (Ferraro 2002), where the park lost a large portion of forest cover during the first few years of boundary marking, due to people fearing that unless they immediately cleared the land that it would be taken away from them by the new protected area. Casse et al. (2005) suggested incentivizing local population to participate in conservation activity by offering an alternative livelihood to farming, which requires new land to be deforested. This is not a new concept, however many attempts at providing alternative livelihoods to local people in forested areas have not been successful (Pollini 2011).

Stopping deforestation through GCF in Makira

The main objectives of GCF are (1) to manage sustainably forest resources in order to maintain the ecological balance and (2) to avoid further destruction of natural resources. Half of the observed GCF sites started their forest resource management in 2004 and the other half in 2006. GCF was expected to help meet long term needs of populations for natural resources and to maintain forest cover to reduce pressure on the Zone of Strict Protection in the Makira PA. The achievement of the conservation objectives hinges on the communities' participation in the protection of their natural environment in the region.

However, there is no indication that rural households have or intend in the future to stop clearing forests (Fig. 5), despite the rules and regulation of GCF. Anjiahely showed the strongest drop in deforestation practices for the sampled year. This is the only slight "success" in terms of stemming deforestation. Interestingly, this was tied in part to the efforts of the community managers reporting on someone clearing a large swath of forest in this area. One person was arrested after the complaints from the COBA reached the police. The drop in deforestation may be due to the fact that households feared further repercussion from the police for land-clearing activities. Thus this "success" may indeed be due to the community monitoring and reporting system in this particular GCF. However, in contrast an adjacent GCF in Sahajinja-manonga had the highest per household forest clearance and 100% of those who claimed they would clear land in the next year followed through with their decision to clear the land. In 2009 and 2010, a WCS field agent was based in the village of Sahajinja-manonga to assist the COBA in better management of their resources. Still, this site had the worst performance in deforestation of all observed sites. This exemplifies the ineffectiveness of GCF.

Forest clearance is part of the agricultural system in the wider Makira area and conservation organizations need to recognize that forest clearance will likely not change without a major shift in approach addressing the problems driving deforestation.

Table 1: Biodiversity richness of Makira Protected Area, compiled from Holmes et al. (2008). Makira forest has the largest number of primate mammals per site in all parks in Madagascar.

Taxonomic group	**Number of species**
Plant (large tree)	222
Bird	101
Amphibian	114
Reptile	62
Mammals (non-primate)	40
Primate (lemur)	21

Table 2: Description of research sample (n = 124), Population census is mostly from an estimation. Many of the total number of COBA members are unknowns, this table indicate a low participation nevertheless.

Villages	**Number of household interviewed**	**Total population (year of census)**	**Member of COBA**
Ambalamahogo	16	1080 (2008)	394
Ambanivalotra	8	395 (2010)	NA
Ampoatsatroka	9	680 (est. 2010)	NA
Andranovolo	15	370 (est. 2009)	NA
Anjiahely	15	310 (est. 2009)	142
Anjiamazava	17	448 (est. 2009)	173
Antseranana	18	516 (est. 2009)	16
Beanana	9	465 (unknown)	NA
Sahajina - man	17	467 (est. 2009)	155

Table 3: Steps to establish a forest management contract with the state government. This table is compiled from the description made by

STEPS	ACTIVITIES	REMARKS
II - Awareness Campaign	Site Selection Village Entry Campaign of awareness	The awareness campaign and the next step require an interval of time of at least a month. Communities need time to reflect.
II - Administrative and socio-organizational processes	Starting the administrative procedures Structuring the community	
III - Development of management tools	Mapping land use Preparation of the socio-economic survey Preparation of ethno botanical survey Forest inventory Development of contract Development of details Development of management plan Development of Dina	
IV - Validation	Restitution of the discussions during the meeting	
V - finalizing of contract	Official ceremony and ritual	The presence of all concerned is desirable for the signature in public even for only a few documents
POST SIGNATURE		
STEPS	**ACTIVITIES**	**NOTICES**
Implementation	Choice of the implementation approach Training of COBA Strengthening/Reinforcement capacities of COGE Institutional support of COBA	Project Team Forestry Administration
Monitoring and assessment	Semi-annual and annual monitoring and assessment Institutional monitoring and assessment	Project Team Authorities administrative Forestry Administration

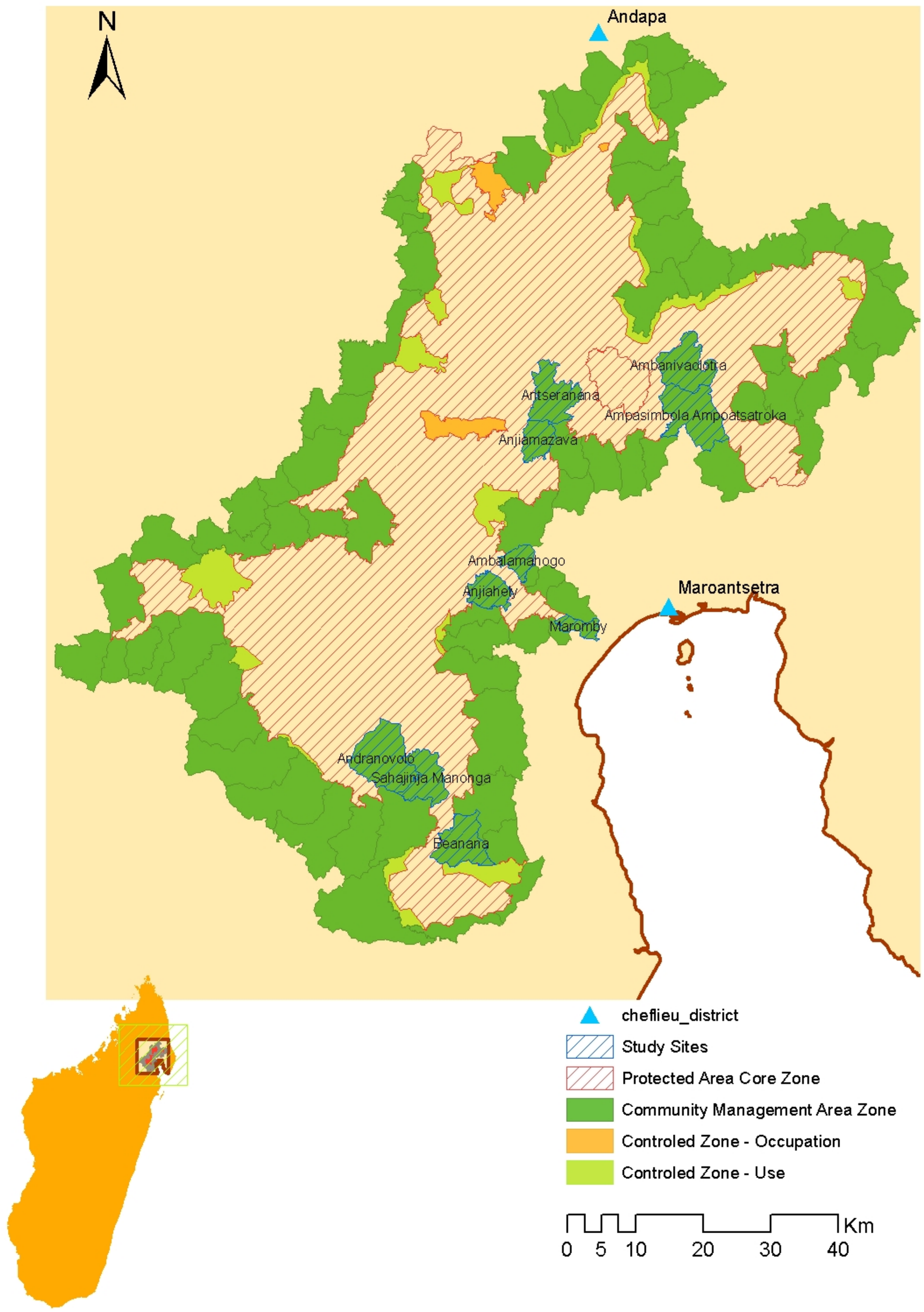

Fig. 1: Makira Protected Area and the Management Transfer Zone. There are about 82 communities living around MPA. Many of them have the access under the Controlled use zone

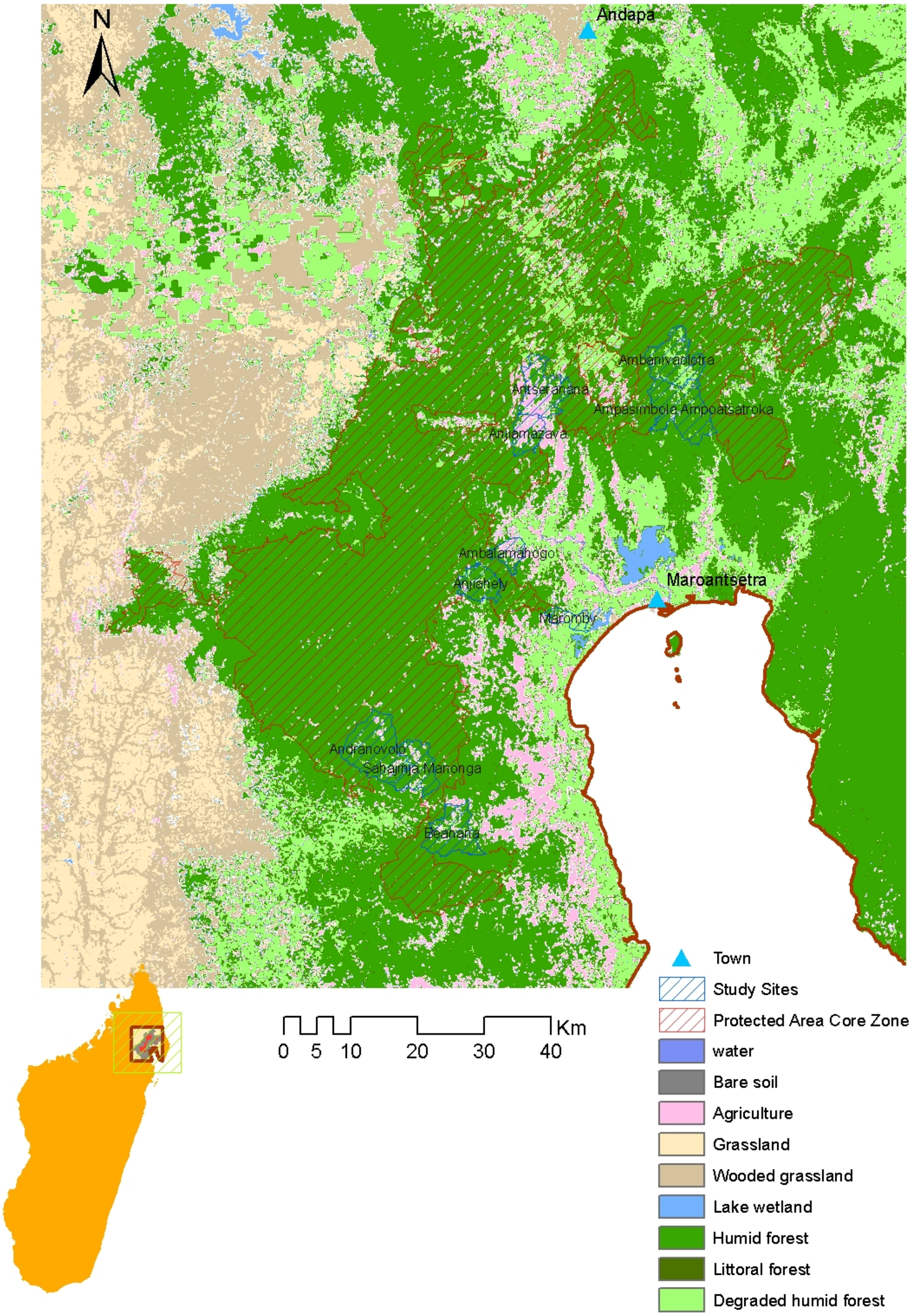

Fig. 2: Land use inside and outside of Makira Protected Area. Heavy deforestations are visible in both sides (west and east) of the Protected Areas.

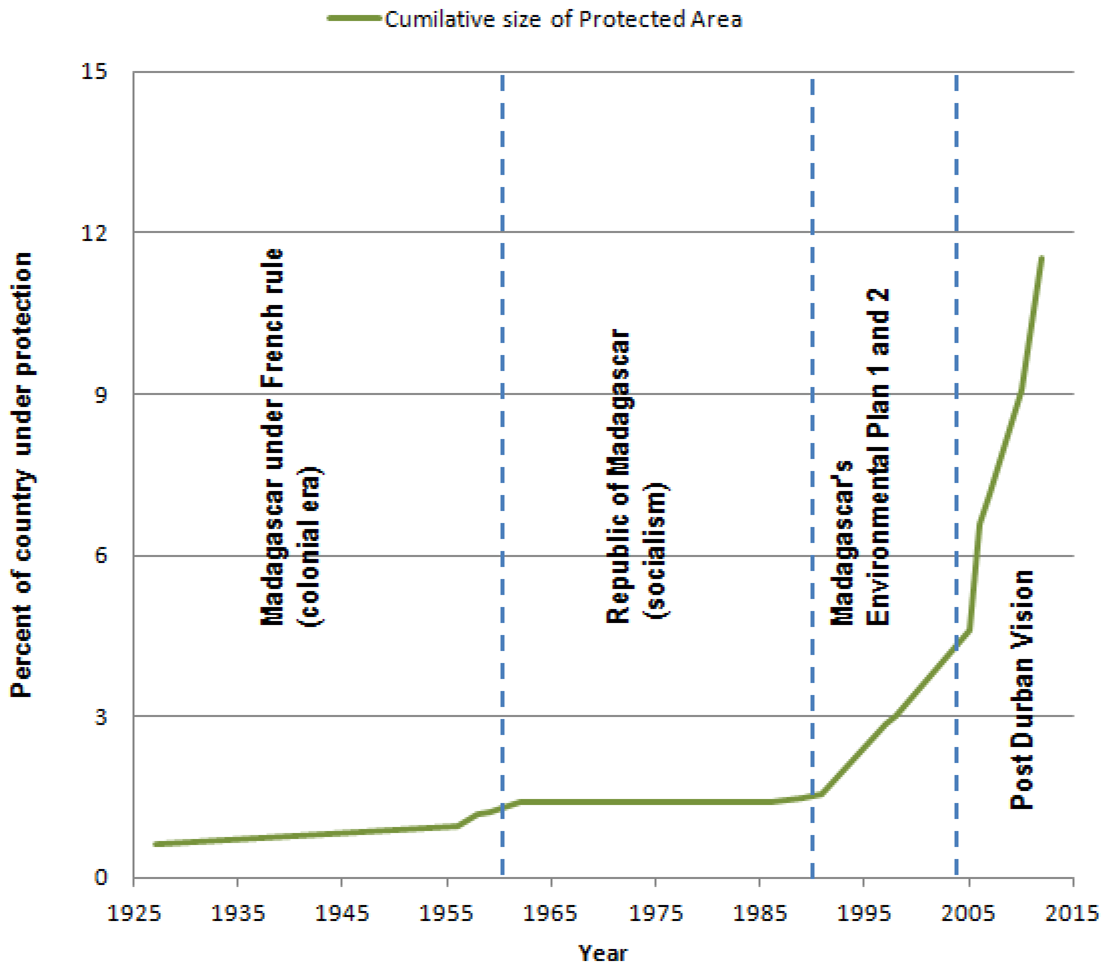

Fig. 3: Establishment of PAs in Madagascar as percentage of the country size. Less than 10% of Madagascar is under protections. Shifts in political system or conservation policy are indicated.

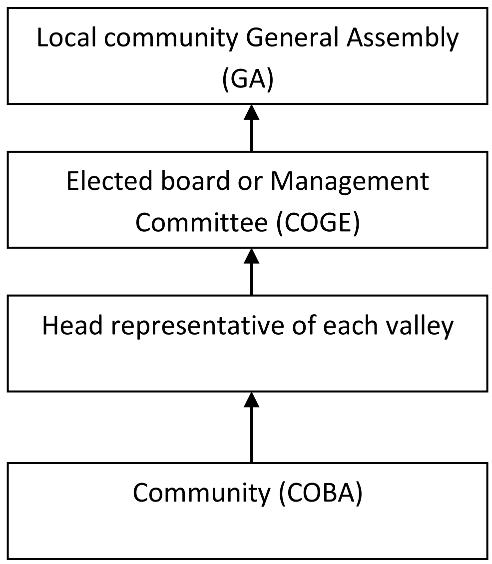

Fig. 4: Simplified structure of the COBA. Decisions are taken by the general assembly and COGE and representative of each valley execute the decision.

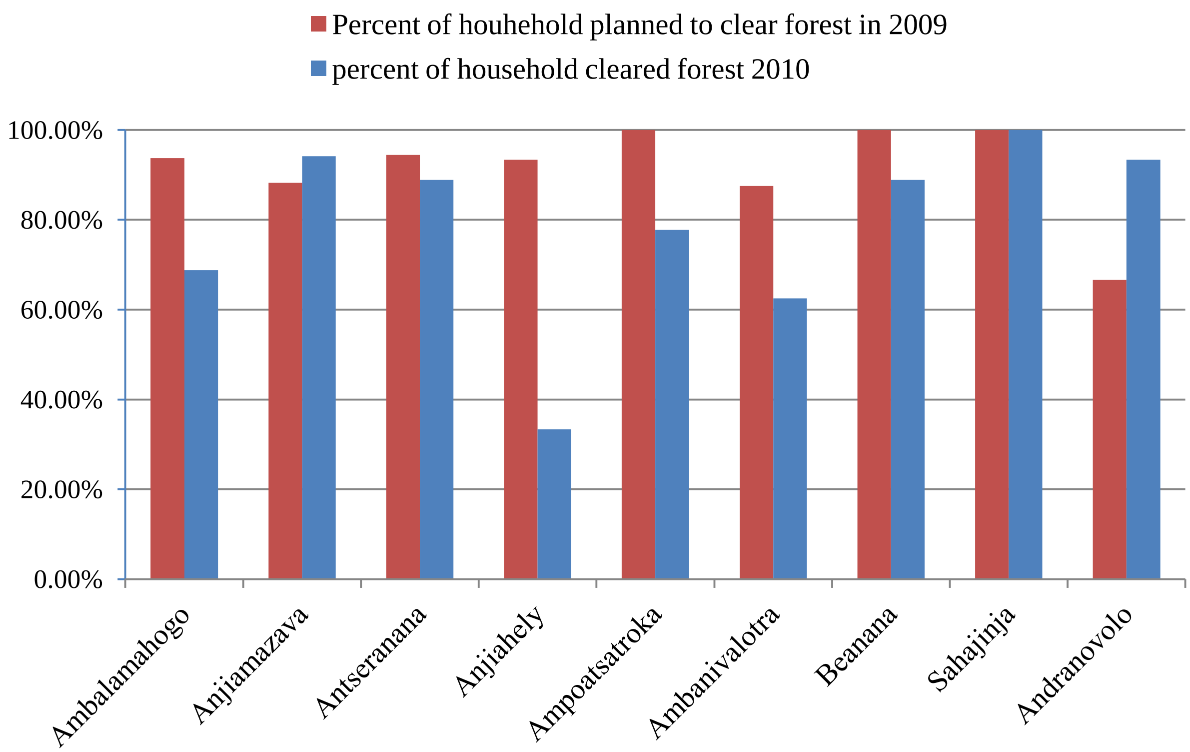

Fig. 5: Comparing household decision in 2009 and follow up of the decision in 2010 on forest clearance. Some of the plots in 2010 were not because the household refused. (Sites are arranged according to distance from the main town, with the closets site being Ambalamahogo and farthest away in Andranovolo)

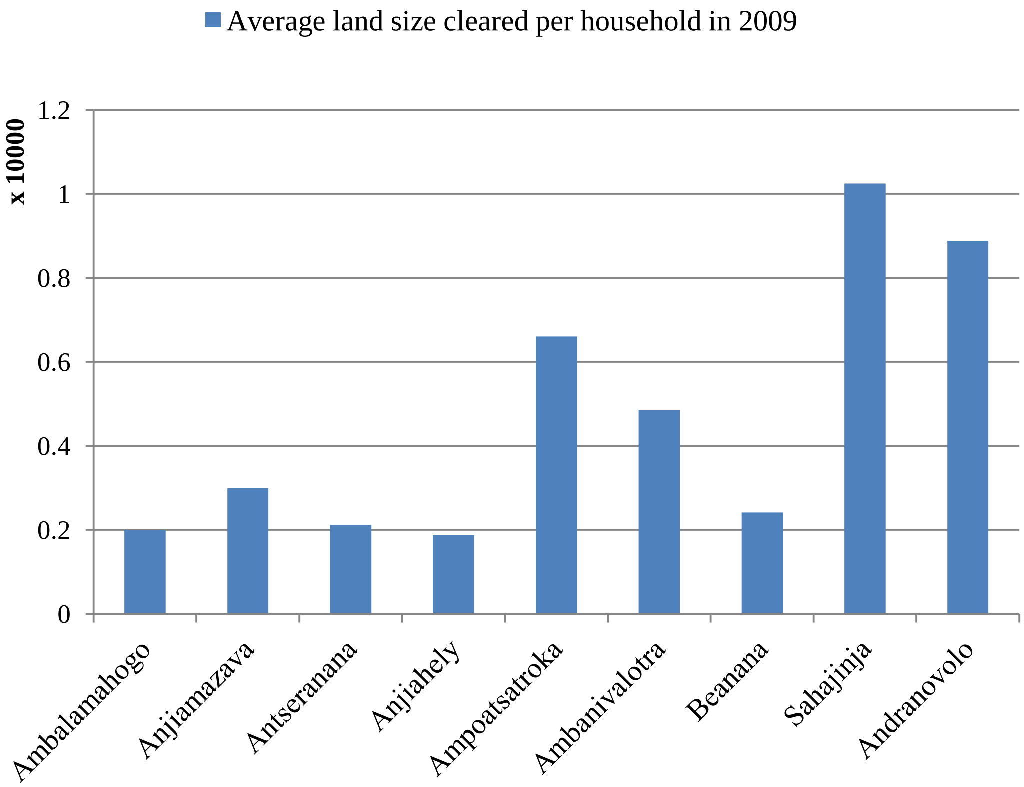

Fig. 6: The average land size cleared in 2009 (in meter square) per household in each GCF sites. Sites are arranged by distance from the main town. (Close to main town in Ambalamahogo and far away in Andranovolo)

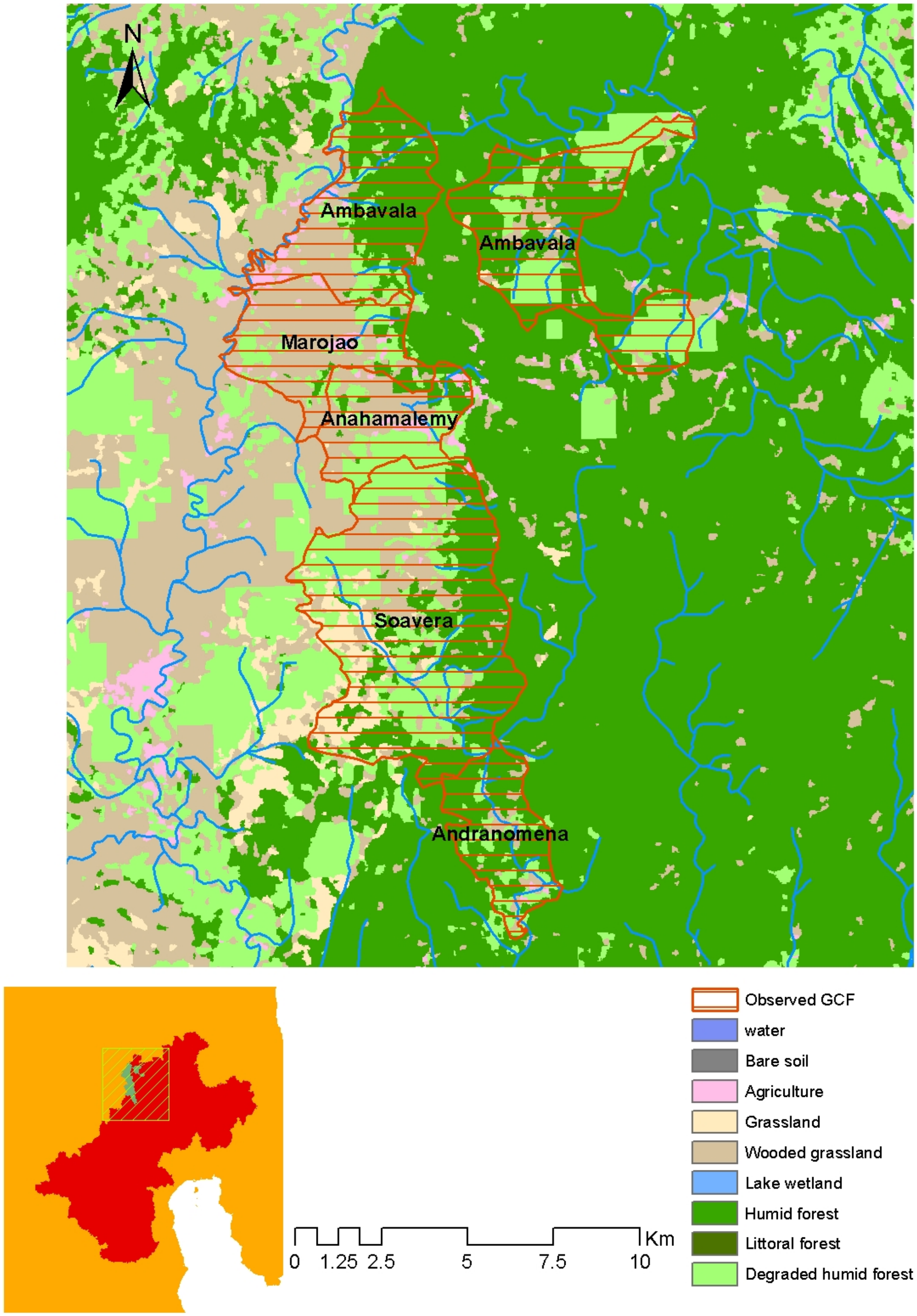

Fig. 7: Observed Community management zone located in the western side of Makira Protected Area.

Chapter V

Conclusion

In chapter II, our analysis illustrated that the most important variables for rice field suitability are the geology type, precipitation and slope. All Combined precipitation variables explained up to 35.3% of the land suitability model, all temperatures variables contributed up to 20.7%. Slope had the second highest contribution with 14.9%, and the model show a declining suitability value as the slope increases. The model identified 6.75 million hectares of suitable land for rice fields under the current climate conditions, which is four times the size of currently cultivated rice fields. Further, future climate change scenarios predicted a gain of suitable land for rice fields over the current climate condition from 6% to 90%. Between 50% and 68% of the current area under rice production would be considered NOT suitable land for production in the future. This is largely due to the shifts in precipitation patterns.

Although, many unknowns exist, e.g. frequency of extreme weather, the application of land use modeling should provide a guide to policy in order to prepare and adapt for future changes, given that further population growth is inevitable and that all future GCMs indicate a warmer and drier future including in Madagascar. A simple and comprehensive analysis of options for adapting to the changing climate is difficult partially due to the unknown adaptive ability of both humans and crops to warmer, drier, or harsher climate conditions. Government can play a crucial role in climate change mitigation and adaptation, however, through research, information, or intervention, as in, for instance, in identifying new varieties of crops or strains that are less sensitive to drought and heat.

In Chapter III, I investigated the effect of adding socio-economic costs into the selection of reserve areas, which has never previously been done in conservation prioritization for Madagascar (Bode et al. 2008a; Kremen et al. 2008 - response to Bode). Socio-economic costs included spatially-explicit variables that proxy for key human-induced land use changes including rice field suitability, burn frequency, and probability of deforestation. The results from this study can be used as a guide for where to focus future conservation efforts, and which areas to avoid. Further, in identifying new areas for biodiversity protection, proposing a reserve network is the beginning rather than the end of the work, and the final solution should result from negotiations between all stakeholders (Knight et al. 2006). By explicitly integrating costs into conservation planning, specifically considering human land uses and needs, it may be possible to better map and design the reserve network to accommodate the needs of local people.

In chapter IV, , I document the application of the new GCF law in a large, biodiversity-rich region in Northeastern Madagascar, the Makira Protected Area, which includes a Community Management Zone in which the GCF is applied. I first examined how the forest management contracts were set up and administered, and then assessed the efficacy of these contracts with respect to institutional effectiveness (Ostrom 1990) and reduction of deforestation, the key driver of biodiversity endangerment in Madagascar (Kremen et al. 2008; Harper et al.

2008). I concluded that, while in theory, CBNRM is a good solution to continuing conservation when a government is weak or overburdened; it is not guaranteed that the local community will have better management of the natural resources and will eventually stop the massive deforestation. It is clear for the case of Makira, installing GCF is way to curtail forest clearing, not transferring management authority to local communities.

Tenure issues can contribute as precursor of forest clearance. Laney (2004) demonstrated that conservation is seen as a threat to the availability of land for future generations. In fact, given the difficulty of obtaining land tenure officially in Madagascar, the only way for people to claim ownership is *via* the traditional practice of clearing the land (Nambena 2003). This is not a new concept, however many attempts at providing alternative livelihoods to local people in forested areas have not been successful (Pollini 2011). Makira Protected Area has failed so far to manage sustainably forest resources in order to maintain the ecological balance in the region and avoid further destruction of natural resources. Forest clearance is part of the agricultural system in the wider Makira area and conservation organizations need to recognize that forest clearance will likely not change without a major shift in approach addressing the problems driving deforestation.

I looked at two different scales of conservation planning: national and regional. At national scale, I attempted to introduce human factors to better map and design the reserve network to accommodate the needs of local people. The result shows that it is possible to use a decision support tools to select an efficient area that meets both human needs and biodiversity habitat. Similarly at regional scale, where the reserve management requires participation from the community, I looked at validity of the conservation policy design. The result shows that while there is a possibility to have a true voluntary participation in community conservation, the current system does not allow that. In conclusion, all attempts to address human need while protecting biodiversity has failed goals: the goal of the reserve network for biodiversity protection and the goal for human well being.

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